APPENDIX A: RISK DATA SHEETS

Risk Title: Accelerated Bone Loss and Fracture Risk

Crosscutting Area :	Human Health and Countermeasures (HHC)
Discipline :	Bone Loss
Risk Number :	1
Risk Description :	Osteoporosis associated with age-related bone loss may occur at an earlier age due to failure to recover bone lost during space flight.
Context / Risk Factors :	This risk may be influenced by age, baseline bone mass density (BMD), gender, nutrition, or muscle loss.
Justification / Rationale :	Crewmembers lose bone during long-duration space flight, especially in weight bearing bones.Calcium and bone metabolism are altered, and failure to recover lost bone (mission- and age related), can lead to increased risk of fractures at a younger age. ISS crewmembers will be affected to varying degrees. Mitigation strategies are under investigation for ISS missions. Bone loss is not considered a significant problem on a 30-day mission to the Moon. Exploration (Mars) crews will be affected to varying degrees.
Risk Rating :	**ISS:** Priority 2 **Lunar:** Priority 3 **Mars:** Priority 2
Current Countermeasures :	• Nutrition • Exercise (resistive and aerobic) • Crew Screening and preparation
Projected Countermeasures or Mitigations & other Deliverables:	• Biophysical modalities [CRL 5] • Crew Screening [CRL 1] • Exercise and fitness regimens [CRL 6-7] • Hormone replacement therapy [CRL 1] • Nutrition [CRL 4] • Pharmacological (including bisphosphonates) [CRL 7] • Rehabilitation strategies [CRL 3] • Spacesuit design [CRL 1] • Artificial gravity
Research & Technology Questions [With Mission Priority]:	

No.	Question
1a	What is the relative risk of sustaining a traumatic and/or stress fracture for a given decrement in bone mineral density, or alteration in bone geometry, in an astronaut-equivalent population who are physically active? **[ISS 3, Lunar 5, Mars 1]**
1b	Will a period of rapid bone loss in hypogravity be followed by a slower rate of loss approaching a basal bone mineral density (BMD)? What are the estimated site-specific fracture risks as one approaches basal BMD? **[ISS 2, Lunar 5, Mars 1]**
1c	Is there an additive or synergistic effect of gonadal hormone deficiency in men or women on bone loss during prolonged exposure to hypogravity? **[ISS 1, Lunar 5, Mars 5]**
1d	What biophysical modalities, nutritional modifications, and pharmacological agents (alone or in combination) will most effectively minimize the decrease in bone mass due to extended hypogravity exposure? **[ISS 1, Lunar 5, Mars 1]**
1e	What are the specifics of the optimal exercise regimen with regard to mode, duration, intensity and frequency, to be followed during exposure to hypogravity so as to minimize decreases in bone mass? Is impact loading an essential element and, if so, how can it be produced in hypogravity? **[ISS 1, Lunar 3, Mars 1]**

	1f	What combination of exercise, biophysical modalities, nutritional modifications, and/or pharmacological agent(s) is most effective, efficient (minimal crew time), and safe in preventing bone loss during exposure to hypogravity? **[ISS 1, Lunar 5, Mars 1]**
	1g	What are the important predictors for estimating site-specific bone loss and fracture risk during hypogravity exposure, including, but not limited to ethnicity, gender, genetics, age, baseline bone density and geometry, nutritional status, fitness level and prior microgravity exposure? **[ISS 1, Lunar 5, Mars 1]**
	1h	Does the hypogravity environment change the nutritional requirements for optimal bone health? **[ISS 3, Lunar 3, Mars 2]**
	1i	What diagnostic tools can be utilized during multi-year missions to monitor and quantify changes in bone mass and bone strength? **[ISS 2, Lunar 5, Mars 1]**
	1j	What systemic adaptations to hypogravity are important contributory factors to bone loss, evaluations of which are essential for effective countermeasure development (e.g., fluid shifts, altered blood flow, immune system adaptations)? **[ISS 3, Lunar 5, Mars 2]**
	1k	Are hypogravity-induced changes in bone density, geometry, and architecture reversible upon encountering partial gravity exposure, or on return to full gravity (1-G)? **[ISS 1, Lunar 5, Mars 1]**
	1l	What regimen (exercise, pharmacological, nutritional, or biomechanical including impact loading or artificial gravity exposure) will most effectively hasten restoration of bone mass and/or bone strength (geometry and architecture) to pre-flight values in returning crewmembers? **[ISS 2, Lunar 5, Mars 2]**

Related Risks :	**Bone Loss**
	Impaired Fracture Healing
	Injury to Joints and Intervertebral Structures
	Renal Stone Formation
	Cardiovascular Alterations
	Diminished Cardiac and Vascular Function
	Immunology & Infection
	Immune Dysfunction, Allergies and Autoimmunity
	Skeletal Muscle Alterations
	Reduced Muscle Mass, Strength, and Endurance
	Sensory-Motor Adaptation
	Impaired Sensory-Motor Capability to Perform Operational Tasks During Flight, Entry, and Landing
	Impaired Sensory-Motor Capability to Perform Operational Tasks After Landing and Throughout Re-Adaptation
	Nutrition
	Inadequate Nutrition
	Clinical Capabilities
	Monitoring and Prevention
	Major Illness and Trauma
	Pharmacology of Space Medicine Delivery
	Rehabilitation on Mars

Important References :	Bikle DD, Sakata T, Halloran BP. The impact of skeletal unloading on bone formation. Gravit Space Biol Bull. 2003 Jun;16(2):45-54. Review. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=12959131

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Risk Title: Impaired Fracture Healing

Crosscutting Area :	Human Health and Countermeasures (HHC)
Discipline :	Bone Loss
Risk Number :	2
Risk Description :	Bone fractures incurred during and immediately after long duration space flight may require a prolonged period for healing, and the bone may be incompletely restored due to changes in bone metabolism associated with space flight.
Context / Risk Factors :	Space flight associated bone loss may increase the risk of traumatic and stress fractures. Inflight risk of injury should be minimized through design of hardware and procedures. Risks may vary between individuals.
Justification / Rationale :	Bone loss associated with space flight may result in additional risk of fracture. Threat to crew health and mission will depend on fracture site, severity and treatment options available. Risk of fracture on ISS is considered extremely low. Risk of fracture on a Lunar mission is low. For a Mars Mission, there is a risk of serious health or performance consequences may be greater because of lack of return capability.
Risk Rating :	**ISS:** Priority 3 **Lunar:** Priority 3 **Mars:** Priority 2
Current Countermeasures :	• Minimize bone loss to lessen fracture risk • Rehabilitation procedures • Crew return capability • Hardware design and procedures to reduce the likelihood of injury

Projected Countermeasures or Mitigations & other Deliverables:	• Biomechanical and pharmacological measures to promote more rapid healing [CRL 5] • Ultrasound and electrical stimulation [CRL 2] [Lunar] [Mars] • Minimize bone loss • Development of treatment options [Lunar] [Mars]

Research & Technology Questions [With Mission Priority]:

No.	Question
2a	Is the rate of fracture healing and the integrity of the healed fracture altered under hypogravity or unloaded conditions? **[ISS 1, Lunar 1, Mars 1]**
2b	Are there site-specific differences or differences in healing diaphyseal bone versus metaphyseal bone under microgravity or partial-gravity conditions? **[ISS 3, Lunar 3, Mars 3]**
2c	Which cellular and biochemical changes in bone cell biology alter fracture healing under microgravity conditions? **[ISS 4, Lunar 4, Mars 4]**
2d	Does the presence of microgravity-induced alteration in bone remodeling and/or osteoporosis affect fracture callus remodeling? **[ISS 2, Lunar 2, Mars 2]**
2e	How do changes in skeletal muscle-bone interactions during space flight contribute to altered fracture healing in microgravity? **[ISS 4, Lunar 4, Mars 4]**
2f	Do biophysical modalities play a role in improving fracture healing in a microgravity environment? **[ISS 2, Lunar 2, Mars 2]**
2g	Do biophysical modalities play a role in improving fracture healing in the presence of bone loss in a microgravity environment? **[ISS 2, Lunar 2, Mars 2]**
2h	Are there anabolic agents, growth factors, or cytokines that will speed fracture repair during microgravity in combination with active bone loss due to unloading? **[ISS 1, Lunar 1, Mars 1]**
2i	What technologies will be used to diagnose fractures of the axial and appendicular skeleton in a space environment? **[ISS 1, Lunar 1, Mars 1]**
2j	Will different technologies be needed to treat either open or closed fractures in a space environment? **[ISS 1, Lunar 1, Mars 1]**

Related Risks :

Bone Loss
Accelerated Bone Loss and Fracture Risk
Injury to Joints and Intervertebral Structures
Renal Stone Formation
Immunology & Infection
Immune Dysfunction, Allergies and Autoimmunity
Skeletal Muscle Alterations
Reduced Muscle Mass, Strength, and Endurance
Sensory-Motor Adaptation
Impaired Sensory-Motor Capability to Perform Operational Tasks During Flight, Entry, and Landing
Impaired Sensory-Motor Capability to Perform Operational Tasks After Landing and Throughout Re-Adaptation
Clinical Capabilities
Monitoring and Prevention
Major Illness and Trauma
Pharmacology of Space Medicine Delivery

Important References :	Durnova GN, Burkovskaia TE, Vorotnikova EV, Kaplanskii AS, Arustamov OV. [The effect of weightlessness on fracture healing of rats flown on the biosatellite Cosmos-2044]. Kosm Biol Aviakosm Med. 1991 Sep-Oct;25(5):29-33. Russian. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=8577136 Kaplansky AS, Durnova GN, Burkovskaya TE, Vorotnikova EV. The effect of microgravity on bone fracture healing in rats flown on Cosmos-2044. Physiologist. 1991 Feb;34(1 Suppl):S196-9. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=2047441 Kirchen ME, O'Connor KM, Gruber HE, Sweeney JR, Fras IA, Stover SJ, Sarmiento A, Marshall GJ. Effects of microgravity on bone healing in a rat fibular osteotomy model. Clin Orthop. 1995 Sep;(318):231-42. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=7671522

Risk Title: Injury to Joints and Intervertebral Structures

Crosscutting Area :	Human Health and Countermeasures (HHC)
Discipline :	Bone Loss
Risk Number :	3
Risk Description :	The risk of fascia, tendon, and/or ligament overuse, and traumatic injury or joint dysfunction upon return to normal/partial gravity may increase due to prolonged mission duration. Hypogravity changes to intervertebral discs may increase the risk of rupture, with attendant back pain, and possible neurological complications.
Context / Risk Factors :	This risk may be influenced by age, loss of muscle strength, state of fitness and conditioning, prior history of injuries, or task related impact on joints and intervertebral structures.
Justification / Rationale :	Hypogravity-induced changes to intervertebral disks and ligaments may increase risk of rupture and/or injury, with attendant back pain, and possible neurological complications. This risk is most significant for a Mars mission.
Risk Rating :	**ISS:** Priority 3 **Lunar:** Priority 2 **Mars:** Priority 2
Current Countermeasures :	• Musculoskeletal Fitness • Post-injury and Post-flight Rehabilitation • Work injury avoidance patterns and design of equipment and tasks to reduce likelihood of injury • Training
Projected Countermeasures or Mitigations & other Deliverables:	• Improved fitness and conditioning regimens
Research & Technology Questions [With Mission Priority]:	

No.	Question
3a	What is the cause of the back pain commonly experienced by crewmembers upon return to 1-G? **[ISS 2, Lunar 3, Mars 2]**
3b	Is damage to joint structure, intervertebral discs, or ligaments incurred during or following hypogravity exposure? **[ISS 2, Lunar 3, Mars 1]**
3c	What countermeasures will protect joint and intervertebral soft tissues (e.g. discs and ligaments) from microgravity or partial gravity-related damage? **[ISS 2, Lunar 2, Mars 1]**
3d	What rehabilitative measures will hasten recovery of soft tissue damage in a partial gravity environments, or upon return to Earth's gravity? **[ISS 2, Lunar 2, Mars 1]**

Related Risks :	**Bone Loss** Accelerated Bone Loss and Fracture Risk Impaired Fracture Healing Renal Stone Formation **Skeletal Muscle Alterations** Reduced Muscle Mass, Strength, and Endurance Increased Susceptibility to Muscle Damage **Sensory-Motor Adaptation** Impaired Sensory-Motor Capability to Perform Operational Tasks During Flight, Entry, and Landing Impaired Sensory-Motor Capability to Perform Operational Tasks After Landing and Throughout Re-Adaptation **Clinical Capabilities** Monitoring and Prevention Major Illness and Trauma
Important References :	Foldes I, Kern M, Szilagyi T, Oganov VS. Histology and histochemistry of intervertebral discs of rats participated in space flight. Acta Biol Hung. 1996;47(1-4):145-56. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=9123987 Foldes I, Szilagyi T, Rapcsak M, Velkey V, Oganov VS. Changes of lumbar vertebrae after Cosmos-1887 space flight. Physiologist. 1991 Feb;34(1 Suppl):S57-8. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=2047467 Hutton WC, Malko JA, Fajman WA. Lumbar disc volume measured by MRI: effects of bed rest, horizontal exercise, and vertical loading. Aviat Space Environ Med. 2003 Jan;74(1):73-8. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=12546302 LeBlanc AD, Evans HJ, Schneider VS, Wendt RE 3rd, Hedrick TD. Changes in intervertebral disc cross-sectional area with bed rest and space flight. Spine. 1994 Apr 1;19(7):812-7. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=8202800 Maynard JA. The effects of space flight on the composition of the intervertebral disc. Iowa Orthop J. 1994;14:125-33. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=7719767 Oganov VS, Cann C, Rakhmanov AS, Ternovoi SK. [Study of the musculoskeletal system of the spine in humans after long-term space flights by the method of computerized tomography] Kosm Biol Aviakosm Med. 1990 Jul-Aug;24(4):20-1. Russian. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=2214660 Pedrini-Mille A, Maynard JA, Durnova GN, Kaplansky AS, Pedrini VA, Chung CB, Fedler-Troester J. Effects of microgravity on the composition of the intervertebral disk. Appl Physiol. 1992 Aug;73(2 Suppl):26S-32S http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=1526953

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Risk Title: Renal Stone Formation

Crosscutting Area :	Human Health and Countermeasures (HHC)
Discipline :	Bone Loss
Risk Number :	4
Risk Description :	The potential for renal stone formation may be increased due to elevated urine calcium concentration associated with bone resorption during exposure to hypogravity and to decreased urine volume during periods of dehydration.
Context / Risk Factors :	This risk may be influenced by environmental factors affecting mineral/fluid status, individual propensity for urine calcium oxalate solubility patterns and stone formation.
Justification / Rationale :	Space flight is associated with changes in urine chemistry (decreased urinary pH and citrate and increased urinary calcium and phosphate) and composition (increased calcium oxalate and brushite saturation, and increased concentration of undissociated uric acid) which likely contribute to the increased renal stone risk observed during and after space flight. Mitigation strategies (potassium citrate) are currently under investigation.
Risk Rating :	**ISS:** Priority 3 **Lunar:** Priority 3 **Mars:** Priority 3
Current Countermeasures :	• Good state of hydration • Nutritional counseling
Projected Countermeasures or Mitigations & other Deliverables:	• Nutrition [CRL 4] • Pharmacological agents (e.g., Potassium or Magnesium Citrate, bisphosphonates) [CRL 4-8] • Urine solubility testing in flight
Research & Technology Questions [With Mission Priority]:	(see table below)
Related Risks :	(see table below)

Research & Technology Questions [With Mission Priority]:

No.	Question
4a	What diagnostic measures permit detection of renal calcification during extended-duration space flight? **[ISS 4, Lunar 1, Mars 1]**
4b	What nutritional and/or pharmacological countermeasures adequately minimize risk of stone formation in-flight and upon return to 1-G? **[ISS 3, Lunar 2, Mars 2]**
4c	What is the time course of increased risk for renal stone formation abating upon return to 1-G? **[ISS 3, Lunar 3, Mars 2]**

Related Risks :

Bone Loss
Accelerated Bone Loss and Fracture Risk
Impaired Fracture Healing
Injury to Joints and Intervertebral Structures
Cardiovascular Alterations
Occurrence of Serious Cardiac Dysrhythmias
Nutrition
Inadequate Nutrition
Clinical Capabilities
Monitoring and Prevention

	Major Illness and Trauma Pharmacology of Space Medicine Delivery
Important References :	Pak CY, Hill K, Cintron NM, Huntoon C. Assessing applicants to the NASA flight program for their renal stone-forming potential. Aviat Space Environ Med. 1989 Feb;60(2):157-61. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=2930428
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Risk Title: Occurrence of Serious Cardiac Dysrhythmias

Crosscutting Area :	Human Health and Countermeasures (HHC)
Discipline :	Cardiovascular Alterations
Risk Number :	5
Risk Description :	Serious cardiac dysrhythmias may occur due to prolonged exposure to hypogravity or asymptomatic cardiac disease.
Context / Risk Factors :	Other physiological changes, such as altered neural and hormonal regulation, diminished cardiac mass and cardiac remodeling, and fluid and electrolyte alterations, may affect occurence of dysrhythmias. Flight duration, gender, and pre-existing cardiovascular disease are also risk factors.
Justification / Rationale :	Cardiac rhythm disturbances have been observed on several occasions during space flight but the occurrence of space flight induced arrhythmias has not been documented. Recent flight and ground-based data demonstrate alterations in cardiac electrical activity, which may indicate altered cardiac electrical stability. If space flight increases the risk of serious cardiac dysrhythmias this could lead to syncope and/or death posing risk both to crewmembers and to the mission.
Risk Rating :	**ISS:** Priority 2 **Lunar:** Priority 2 **Mars:** Priority 2

Current Countermeasures :	• Resuscitation equipment, including onboard defibrillator • Crew medical screening • Onboard monitoring
Projected Countermeasures or Mitigations & other Deliverables:	• Electrical cardioversion (Equipment currently on board, efficacy not demonstrated in space environment) [CRL 1] • Nutritional countermeasure [CRL 2] • Pharmaceutical countermeasure [CRL 1] • Pre-flight and in-flight testing and monitoring to assess altered susceptibility to dysrhythmias [CRL 7]

Research & Technology Questions [With Mission Priority]:

No.	Question
5a	Does space flight increase susceptibility to serious cardiac dysrhythmias? **[ISS 1, Lunar 1, Mars 1]**
5b	What conditions of space flight (e.g., microgravity, disruption of physiological rhythms, nutrition, environmental factors and radiation) may be responsible for cardiac dysrhythmias, and what are the mechanisms involved? **[ISS 1, Lunar 1, Mars 1]**
5c	Can risk of serious cardiac dysrhythmias be predicted for individual crewmembers? **[ISS 1, Lunar 1, Mars 1]**
5d	What countermeasures may prevent or reduce the occurrence of serious cardiac dysrhythmias during long-term space flight? **[ISS 1, Lunar 1, Mars 1]**
5e	Can susceptibility to, and occurrence of, serious cardiac dysrhythmias be effectively diagnosed and treated during space flight? **[ISS 1, Lunar 1, Mars 1]**
5f	Which cardiovascular diseases are likely to be aggravated by space flight, and what mechanisms are involved? **[ISS 1, Lunar 1, Mars 1]**
5g	What screening methods on the ground and in-flight might identify crewmembers with underlying cardiovascular disease, which may be aggravated by space flight? **[ISS 1, Lunar 1, Mars 1]**

Related Risks :

Cardiovascular Alterations
Diminished Cardiac and Vascular Function
Environmental Health
Define Acceptable Limits for Contaminants in Air and Water
Skeletal Muscle Alterations
Reduced Muscle Mass, Strength, and Endurance
Increased Susceptibility to Muscle Damage
Nutrition
Inadequate Nutrition
Clinical Capabilities
Monitoring and Prevention
Major Illness and Trauma
Pharmacology of Space Medicine Delivery
Ambulatory Care
Rehabilitation on Mars
Radiation
Acute and Late CNS Risks

	Chronic and Degenerative Tissue Risks Acute Radiation Risks
Important References :	Fritsch-Yelle JM, Leuenberger UA, D'Aunno DS, Rossum AC, Brown TE, Wood ML, Josephson ME, Goldberger AL. An Episode of Ventricular Tachycardia During Long-Duration Spaceflight. The American Journal of Cardiology. 1998 June;81: 1391-1392. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=9631987 Smith RF, Stanton K, Stoop D, Brown D, Januez W, King P. Vectorcardiographic Changes During Extended Space flight (M093): Observations at Rest and During Exercise. In: Biomedical Results of Skylab (NASA SP-377). Johnston RS and Dietlein LF, editors. Washington, DC: NASA 339-350, 1977. Rossum AC, Wood ML, Bishop Sl, Deblcok H, Charles JB. Evaluation of Cardiac Rhythym Disturbances During Extravehicular Activity. The American Journal of Cardiology. 1997 April;79: 1153-1155. Charles JB, Bungo MW, Fortner GW. Cardiopulmonary Function. In: Nicogossian A, Huntoon C, Pool S, and (editors). Space Physiology and Medicine. 3rd ed. Philadelphia, PA: Lea & Febiger, 286-304, 1994.

Risk Title: Diminished Cardiac and Vascular Function

Crosscutting Area :	Human Health and Countermeasures (HHC)
Discipline :	Cardiovascular Alterations
Risk Number :	6
Risk Description :	Diminished cardiac function, orthostatic or postural hypotension, and the impaired ability to perform strenuous tasks on a planetary surface may occur due to prolonged exposure to hypogravity.
Context / Risk Factors :	This risk may be influenced by altered neural and hormonal regulation, flight duration, or gender.
Justification / Rationale :	Some, but not all, studies suggest that prolonged exposure to microgravity may lead to reduction of cardiac mass and reduced cardiac function. Carefully controlled inflight studies are required to document this finding and determine the clinical signficance.
Risk Rating :	**ISS:** Priority 2 **Lunar:** Priority 2 **Mars:** Priority 2
Current Countermeasures :	• In flight exercise
Projected Countermeasures or Mitigations & other Deliverables:	• Artificial G exposure • Drugs that affect cardiac mass and function • Improved exercise and conditioning program
Research & Technology Questions [With Mission Priority]:	

No.	Question
6a	Does long-duration space flight lead to diminished cardiac function? If so, what mechanisms are involved? **[ISS 1, Lunar 1, Mars 1]**
6b	Is space flight induced diminished cardiac function reversible? **[ISS 1, Lunar 1, Mars 1]**
6c	What is the extent of reduction in cardiac function and/or mass associated with long-duration space flight? **[ISS 1, Lunar 1, Mars 1]**
6d	Can susceptibility to reduced cardiac function be predicted for individual crewmembers? **[ISS 2, Lunar 2, Mars 2]**

	6e	What countermeasures may be effective in mitigating the occurrence of reduced cardiac function or mass? **[ISS 1, Lunar 1, Mars 1]**
	6f	What are the physiological and environmental factors by which space flight decreases orthostatic tolerance? **[ISS 1, Lunar 1, Mars 1]**
	6g	How does duration of space flight affect the severity and time course of orthostatic intolerance, and what are the mechanisms? **[ISS 2, Lunar 2, Mars 2]**
	6h	Is orthostatic intolerance likely to develop on the surface of Mars or the moon? **[ISS 1, Lunar 1, Mars 1]**
	6i	Can space flight induced orthostatic intolerance be predicted for individual crewmembers? **[ISS 1, Lunar 1, Mars 1]**
	6j	What countermeasures can be developed to overcome or prevent orthostatic intolerance? **[ISS 1, Lunar 1, Mars 1]**
	6k	What are the physiological and environmental factors by which space flight decreases aerobic exercise capacity? **[ISS 1, Lunar 1, Mars 1]**
	6l	Is the observed decrease in exercise capacity directly related to duration of space flight? **[ISS 1, Lunar 1, Mars 1]**
	6m	Can the degree of reduced aerobic exercise capacity be predicted for individual crewmembers? **[ISS 1, Lunar 1, Mars 1]**
	6n	What countermeasures can be developed to overcome microgravity-induced reduction in aerobic exercise capacity? **[ISS 1, Lunar 1, Mars 1]**

Related Risks :	**Bone Loss**
	Accelerated Bone Loss and Fracture Risk
	Injury to Joints and Intervertebral Structures
	Cardiovascular Alterations
	Occurrence of Serious Cardiac Dysrhythmias
	Environmental Health
	Define Acceptable Limits for Contaminants in Air and Water
	Skeletal Muscle Alterations
	Reduced Muscle Mass, Strength, and Endurance
	Increased Susceptibility to Muscle Damage
	Clinical Capabilities
	Monitoring and Prevention
	Major Illness and Trauma
	Pharmacology of Space Medicine Delivery
	Ambulatory Care
	Rehabilitation on Mars
Important References :	Blomqvist LD, Lane CG, Wright SJ, Meny GM, Levine BD, Buckey JC, Peshock RM, Weatherall P, Stray-Gundersen J, Gaffney FA, Watenpaugh DE, Arbeille P, and Baisch F. Cardiovascular regulation in microgravity. In: Scientific Results of the German Spacelab Mission D-2: Proceedings of the Norderney Symposium, edited by Sahm PR, Keller MH, and Schiewe B.. Koln, Germany: Wissenschaftliche Projektfuhrung D-2 (c/o Deutsches Zentrum fur Luft- und Raumfahrt), 1994, p. 688-690.
	Charles JB, Frey MA, Fritsch-Yelle JM, Fortner GW. Cardiovascular and Cardiorespiratory Function. In Huntoon C, Antipov V, Grigoriev A (editors), Volume III, Book I (humans in Space) Space Biology and Medicine, AIAA, Reston, VA, 1996.
	The Neurolab Spacelab Mission: Neuroscience Research in Space: Results from the STS-90 Neurolab Spacelab Mission: Section 4 Blood Pressure Control. pp. 171-205. Buckey J and Homick J (editors). NASA SP-2003-535, 2003.

Risk Title: Define Acceptable Limits for Contaminants in Air and Water

Crosscutting Area :	Human Health and Countermeasures (HHC)
Discipline :	Environmental Health
Risk Number :	7
Risk Description :	Crew health and performance may be jeopardized due to the inability to define acceptable limits for contaminants.
Context / Risk Factors :	This risk may be influenced by remoteness, crew health, or crew susceptibility to degree of system closure.
Justification / Rationale :	Excessive pollutant levels (including microbial contaminants) can jeopardize crew health and/or impair mission success. The severity and likelihood of any adverse effects depends on the specific pollutant and its measured concentration.
Risk Rating :	**ISS:** Priority 3 **Lunar:** Priority 2 **Mars:** Priority 1
Current Countermeasures :	• Identification of possible contaminants • Restriction on types of materials allowed in flight • Preflight off-gassing of certain materials
Projected Countermeasures or Mitigations & other Deliverables:	• Identification of possible contaminants
Research & Technology Questions [With Mission Priority]:	(see table below)

No.	Question
7a	What are the most likely sources of severe air and water pollution specific to ISS, lunar, and Mars missions, and what methods can be used to control these sources over long periods of time? **[ISS 1, Lunar 1, Mars 1]**
7b	What are the tolerance limits in terms of quantity and type of microorganisms in air, water, and food, and on surfaces? **[ISS 1, Lunar 1, Mars 1]**
7c	What approaches to setting exposure standards may be used when insufficient data are available to allow prediction of acceptable exposure levels? **[ISS 1, Lunar 1, Mars 1]**
7d	What is the requirement for determining how rapidly acceptable air quality can be recovered after a severe pollution condition and what effect that recovery has on humidity condensate and the water recovery system? **[ISS 1, Lunar 1, Mars 1]**
7e	Can automated real-time systems be used to monitor air and water quality for lunar and Mars missions, and can the crew interpret results without ground support? **[ISS 1, Lunar 1, Mars 1]**
7f	How can traditional limited-time exposure and human toxicological data be used to predict acceptable values for inhalation exposures to single chemicals and/or mixtures? **[ISS 2, Lunar 2, Mars 2]**
7g	What impact do space flight induced, biological, physiological, and immunological changes have on the susceptibility of crewmembers to infectious agents and toxic substances in the air and water? **[ISS 2, Lunar 2, Mars 2]**
7h	What are the effects of exposure to ultra fine and larger (respirable and non-respirable) particles (e.g., lunar dust) on crew health, safety and performance? **[ISS 3, Lunar 2, Mars 2]**
7i	What are the interactions of microbes, chemicals and plants in CELSS on air quality? **[ISS 3, Lunar 2, Mars 2]**
7j	To the extent that plants are critical to mission success, will the potential for phytotoxicity be adequately addressed in the evaluation of air quality? **[ISS 3, Lunar 3, Mars 2]**

	7k — Is there potential for increased heterogeneity in terms of the distribution of air contaminants in the relatively larger lunar and Mars habitats? If so, what additional monitoring resources and/or strategies are necessary to protect crew health? **[ISS 3, Lunar 2, Mars 2]**
Related Risks :	**Immunology & Infection** Immune Dysfunction, Allergies and Autoimmunity Interaction of Space flight Factors, Infections and Malignancy Alterations in Microbes and Host Interactions **Advanced Environmental Monitoring & Control** Monitor Air Quality Monitor External Environment Monitor Water Quality Monitor Surfaces, Food, and Soil Provide Integrated Autonomous Control of Life Support Systems **Advanced Extravehicular Activity** Provide Space Suits and Portable Life Support Systems **Advanced Food Technology** Maintain Food Quantity and Quality **Advanced Life Support** Maintain Acceptable Atmosphere Maintain Thermal Balance in Habitable Areas Provide and Maintain Bioregenerative Life Support Systems
Important References :	Huntoon CL. Toxicological Analysis of STS-40 Atmosphere, NASA/JSC Memorandum, SD4/01-93-251, July 6, 1991; Toxicological Analysis of STS-55 Atmosphere, NASA/JSC Memorandum SD4-93-251, July 6, 1993. James JT. Toxicological Assessment of Air Contaminants during the Mir 19 Expedition, 1996 James JT. Toxicological Assessment of Air Samples Taken after the Oxygen-Generator Fire on Mir, NASA/JSC Memorandum SD2-97-513, April 10, 1997 Nicogossian AE, et al. Crew Health in the Apollo-Soyuz Test Project Medical Report, NASA SP-411, 1977 Pool SL. Ethylene Glycol Treatise. NASA/JSC Memorandum SD2-97-542, September 15, 1997.

Risk Title: Immune Dysfunction, Allergies and Autoimmunity

Crosscutting Area :	Human Health and Countermeasures (HHC)
Discipline :	Immunology & Infection
Risk Number :	8
Risk Description :	Atopic and autoimmune diseases may occur due to long-term space flight effects on immune-regulatory pathways or on specific immune cells.
Context / Risk Factors :	This risk may be influenced by radiation, microgravity, isolation, stress (e.g., sleep deprivation, extreme environments, and nutritional deprivation), or crewmember genetics.
Justification / Rationale :	In vitro studies have demonstrated that contributing risk factors of space flight collectively have a powerful effect upon the cells of the immune system: T cells, particularly CD4+ (helper) T cells, B cells, NK cells, monocyte/ macrophages/dendritic cells, hematopoietic stem cells and cytokine networks can be negatively affected. Alterations in one or more immune system regulatory network (i.e. cells or cell products) could affect homeostasis, which could result in allergic (atopic) or autoimmune disease. The relatively short time of the lunar mission (10-44 days) would tend to

<table>
<tr><td></td><td>reduce the risk of developing immunodeficiency or atopic disease. The long-term exposure (>1 year) to deep-space radiation, to microgravity (> 2 years), and to other conditions of space flight during a Mars mission would offer the greatest challenge to the host immune system.</td></tr>
<tr><td>Risk Rating :</td><td>ISS: Priority 2
Lunar: Priority 2
Mars: Priority 2</td></tr>
<tr><td>Current Countermeasures :</td><td>• Assessment of crewmembers for prior autoimmune or atopic disorders.
• Radiation shielding
• Monitor and limit exposure to radiation and other environmental factors</td></tr>
<tr><td>Projected Countermeasures or Mitigations & other Deliverables:</td><td>• Definition of surrogate markers of immune function that will allow for the monitoring of immune cells and/or immune system compartments during a long-duration space flight
• Definition of the background of crewmembers to identify individuals more likely to develop autoimmune or atopic disease
• Detection systems for assessment of immune function [CRL 2]</td></tr>
<tr><td>Research & Technology Questions [With Mission Priority]:</td><td>
<table>
<tr><th>No.</th><th>Question</th></tr>
<tr><td>8a</td><td>What are the molecular and genetic mechanisms that are affected by space flight related environments (e.g., radiation, microgravity, stress, isolation, sleep deprivation, extreme environments, nutritional deficiency, and social interactions) that can result in the loss of immunoregulation/immune tolerance and/or affect innate/acquired immunity, respectively? [ISS 1, Lunar 1, Mars 1]</td></tr>
<tr><td>8b</td><td>Can the effects on immune function (innate/acquired immunity), or dysfunction (loss of tolerance/immune surveillance) be summarized as a consequence of the conditions relating to each mission and/or its duration (i.e., 1-year ISS, 30-day lunar, 30-month Mars)? [ISS 1, Lunar 1, Mars 1]</td></tr>
<tr><td>8c</td><td>What autoimmune diseases or allergies may affect astronauts exposed to space flight environments of different missions and/or durations? [ISS 1, Lunar 1, Mars 1]</td></tr>
<tr><td>8d</td><td>Are there detection systems that can identify the first alterations in immune regulatory networks (identify surrogate markers of immune function/dysfunction) so that therapeutic interventions can be instituted? [ISS 2, Lunar 2, Mars 2]</td></tr>
<tr><td>8e</td><td>What steps can be taken during space flight to modify immune function as it relates to autoimmunity or atopic disease? [ISS 2, Lunar 2, Mars 2]</td></tr>
<tr><td>8f</td><td>Will it be possible to use immuno-regulatory agents to prevent immune imbalances with respect to the development of atopic or autoimmune diseases? [ISS 1, Lunar 1, Mars 1]</td></tr>
<tr><td>8g</td><td>Will nutritional supplements be able to modify immune responses by working in concert with other immuno-modulators to reduce atopic and/or autoimmune disease? [ISS 1, Lunar 1, Mars 1]</td></tr>
<tr><td>8h</td><td>What pharmalogical agents used during long-term space flights, or interactions between pharmalogical agents, negatively affect the immune system? [ISS 1, Lunar 1, Mars 1]</td></tr>
</table>
</td></tr>
<tr><td>Related Risks :</td><td>
<table>
<tr><td>Environmental Health</td></tr>
<tr><td>Define Acceptable Limits for Contaminants in Air and Water</td></tr>
<tr><td>Immunology & Infection</td></tr>
<tr><td>Interaction of Space flight Factors, Infections and Malignancy</td></tr>
<tr><td>Alterations in Microbes and Host Interactions</td></tr>
<tr><td>Nutrition</td></tr>
<tr><td>Inadequate Nutrition</td></tr>
<tr><td>Clinical Capabilities</td></tr>
</table>
</td></tr>
</table>

	Monitoring and Prevention Major Illness and Trauma Pharmacology of Space Medicine Delivery Ambulatory Care Rehabilitation on Mars **Behavioral Health & Performance and Space Human Factors (Cognitive)** Human Performance Failure Due to Poor Psychosocial Adaptation Human Performance Failure Due to Neurobehavioral Problems Mismatch between Crew Cognitive Capabilities and Task Demands Human Performance Failure Due to Sleep Loss and Circadian Rhythm Problems **Radiation** Carcinogenesis Acute and Late CNS Risks Chronic and Degenerative Tissue Risks Acute Radiation Risks **Advanced Food Technology** Maintain Food Quantity and Quality
Important References :	Aviles H, Belay T, Vance M, Sonnenfeld G. Increased levels of catecholamines correlate with decreased function of the immune system in the hindlimb-unloading rodent model of spaceflight (Abstract 107). Gravit Space Biol Bull. 17:56, 2003. Chinen J, Shearer WT. Immunosuppression induced by therapeutic agents and by environmental conditions. In Stiehm ER, ed. Immunologic disorders in infants and children, 5th Edition. Philadelphia: WB Saunders, in press, 2004. Chitnis T, Khoory SJ. Role of costimulatory pathways in the pathogenesis of multiple sclerosis and experimental autoimmune encephalitis. J Allergy Clin Immunol. 112:837-849, 2003. Dicello JF. The impact of the new biology on radiation risks in space. Health Phys. 85:94-102, 2003. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=12861962 Dicello JP. Cucinotta FA. Space radiation. Shankar Vinala Art No. sst036:1-8, 2003. Fedorenko B, Druzhinin S, Yudaeva L, Petrov V,Akatov Y, Snigiryova G, Novitskaya N, Shevchenko V, and Rubanovich A. Cytogenetic studies of blood lymphocytes from cosmonauts after long-term space flights on Mir station. Adv Space Res. 27(2):355-9, 2001. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=11642297 Graczyk PP. Caspase inhibitors as anti-inflammatory and antiapoptotic agent. Prog Med Chem. 39:1-72, 2003 http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=12536670 Greeneltch KM, Haudenschild CC, Keegan AD, Shi Y. The opioid antagonist naltrexone blocks acute endotoxic shock by inhibiting tumor necrosis factor-alpha production. Brain Behav Immun. 18(5):476-84, 2004. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=15265541

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Risk Title: Interaction of Space flight Factors, Infections and Malignancy

Crosscutting Area :	Human Health and Countermeasures (HHC)
Discipline :	Immunology & Infection
Risk Number :	9
Risk Description :	Increased risk of infections or cancers may result from immune dysfunction caused by the interaction of space flight factors.
Context / Risk Factors :	In addition to space flight related immune dysfunction, which can increase the risk of infections in crewmembers, microgravity can also affect microorganisms in a variety of ways. Furthermore, several neoplastic malignancies have been associated with a variety of human pathogens. This risk may be influenced by immune dysfunction, latent viral infections, commensal organisms, or host genetics.
Justification / Rationale :	Every component of immune resistance to infection is compromised under space flight conditions. As a result, bacterial, fungal, or viral infections may be more likely in space flight environments (though this has not been documented). In particular, latent viruses (e.g., Epstein-Barr virus, herpes simplex, polyomaviruses, and Hepatitis viruses) can become active and potentially initiate tumor formation. The length and severity of space flight conditions on the Martian mission are expected to pose the highest (though still low probability) risk for the development of immune cell-mediated leukemias and lymphomas.

<table>
<tr><td>Risk Rating :</td><td>ISS: Priority 2
Lunar: Priority 3
Mars: Priority 2</td></tr>
<tr><td>Current Countermeasures :</td><td>
Pre-flight quarantine (Health Stabilization Program)
Radiation shielding.
Monitoring exposure to radiation and other environmental factors
Ongoing crew health monitoring
Onboard antibiotics, anti-viral and anti-fungal agents, immunizations, sterilization procedures, use of clean vehicles
Air and water monitoring
Regular inflight 'housecleaning'
</td></tr>
<tr><td>Projected Countermeasures or Mitigations & other Deliverables:</td><td>
Anti-microbial agents [CRL 4]
Fusion proteins to block virus re-infection [CRL 6]
Molecular detection systems for surface, water and airborne pathogens (See AHST Risks 34, 36, & 37) [CRL 7]
Molecular diagnostic/detection kits and equipment to classify infectious agents [CRL 6]
Pathogen-specific immunizations [CRL 2]
Pre-flight crew screening for the presence of microorganisms [CRL 2]
</td></tr>
<tr><td>Research & Technology Questions [With Mission Priority]:</td><td><table>
<tr><th>No.</th><th>Question</th></tr>
<tr><td>9a</td><td>What types of latent infections (e.g., viral infections) will become reactivated as a function of space flight associated factors and pose the greatest threat to human health as a function of compromised immunity resulting from space travel? [ISS 1, Lunar 1, Mars 1]</td></tr>
<tr><td>9b</td><td>What commensal organisms have the potential of establishing a primary infection and pose the greatest threat to human health as a function of compromised immunity resulting from space travel? [ISS 1, Lunar 1, Mars 1]</td></tr>
<tr><td>9c</td><td>What diagnostic, environmental monitoring, or laboratory technologies need to be developed for the identification of pathogenic microorganisms, and prevention or diagnosis of infectious diseases while in space (e.g., bacterial, viral, or fungal typing in real-time)? [ISS 1, Lunar 1, Mars 1]</td></tr>
<tr><td>9d</td><td>Will the severity of disease(s) resulting from latent infection reactivation, and/or infections caused by commensal organisms (as a function of space flight associated factors), be affected by the space mission and/or its duration (i.e., 1-year ISS, 30-day lunar, 30-month Mars)? [ISS 1, Lunar 1, Mars 1]</td></tr>
<tr><td>9e</td><td>Are there neoplastic malignancies that may result from latent infection reactivation, and/or infections caused by commensal organisms (as a function of space flight associated factors), that will be affected by the space mission and/or its duration? [ISS 2, Lunar 2, Mars 2]</td></tr>
<tr><td>9f</td><td>Is it possible to predict the summary effects of each component condition and duration of space flight that results in an infectious and/or neoplastic state? [ISS 2, Lunar 2, Mars 2]</td></tr>
<tr><td>9g</td><td>Will it be possible to develop nutritional supplements to augment anti-microbial and/or anti-tumor therapies? [ISS 2, Lunar 2, Mars 2]</td></tr>
<tr><td>9h</td><td>Will it be possible to restore immunity in a severely immunocompromised astronaut with autologous stem cell transplants? [ISS 3, Lunar 3, Mars 3]</td></tr>
</table></td></tr>
</table>

	9i — What steps can be taken during space flight to boost immune function, and what antimicrobial therapies and immunological treatments can be used to prevent or cure infections? **[ISS 2, Lunar 2, Mars 2]** 9j — Will it be possible to use anti-viral, -bacterial, or -fungal agents aboard spaceships to reduce pathogen burdens or to treat infections? **[ISS 2, Lunar 2, Mars 2]** 9k — Will therapeutic agents aboard spacecraft function to reduce or treat tumor development? **[ISS 3, Lunar 3, Mars 3]**
Related Risks :	**Environmental Health** Define Acceptable Limits for Contaminants in Air and Water **Immunology & Infection** Immune Dysfunction, Allergies and Autoimmunity Alterations in Microbes and Host Interactions **Nutrition** Inadequate Nutrition **Clinical Capabilities** Monitoring and Prevention Major Illness and Trauma Pharmacology of Space Medicine Delivery Ambulatory Care Rehabilitation on Mars **Behavioral Health & Performance and Space Human Factors (Cognitive)** Human Performance Failure Due to Sleep Loss and Circadian Rhythm Problems **Radiation** Carcinogenesis Acute and Late CNS Risks Chronic and Degenerative Tissue Risks Acute Radiation Risks **Advanced Environmental Monitoring & Control** Monitor Surfaces, Food, and Soil **Advanced Food Technology** Maintain Food Quantity and Quality
Important References :	Aviles H, Belay T, Fountain K, Vance M, Sonnenfeld G. Increased susceptibility to Pseudomonas aeruginosa infection hindlimb unloading conditions. J Appl Physiol. 95:73-80, 2003. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=12626488 Aviles H, Belay T, Fountain K, Vance M, Sun B, Sonnenfeld G. Active hexose correlated compound enhances resistance to Klebsiella pneumoniae infection in mice in the hindlimb-unloading model of spaceflight conditions. J Appl Physiol. 95:491-496, 2003. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=12692142 Belay T, Aviles H, Pyle B, Sonnenfeld G. Decreased production of exotoxin A during enhanced growth of Pseudomonas aeruginosa in serum-sapi medium supplemented with norepinephrine (Abstract 57). Gravit Space Biol Bull. 17:27, 2003.

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Risk Title: Alterations in Microbes and Host Interactions

Crosscutting Area :	Human Health and Countermeasures (HHC)
Discipline :	Immunology & Infection
Risk Number :	10
Risk Description :	Alterations in microbes and host interactions due to exposure to space flight conditions may result in previously innocuous microorganisms endangering the crew and life support systems.
Context / Risk Factors :	This risk may be influenced by extreme environments, isolation, microbial contamination, microgravity, nutritional deprivation, radiation, sleep deprivation, or stress.
Justification / Rationale :	Long-duration space flight may result in alterations in the host/microbe relationship that may lead to a difficult to control, or severe, infection. In particular, the long-duration and severe nature of space flight conditions on a Mars mission might increase the risk. The short-duration of the Lunar mission is not likely to provide sufficient time for significant alterations in the host/microbe relationship.
Risk Rating :	**ISS:** Priority 3 **Lunar:** Priority 3 **Mars:** Priority 2
Current Countermeasures :	• In-flight environmental monitoring and bioburden reduction procedures (cleaning, filtering etc.)
Projected Countermeasures or Mitigations & other Deliverables:	• Comprehensive microbial identification technology [CRL 5] • Pre-flight screening [CRL 7] • Routine in-flight microbial identification/monitoring capability [CRL 6]
Research & Technology Questions [With Mission Priority]:	

No.	Question
10a	What technologies will monitor, detect, quantify or identify microorganisms that pose a threat to human health during a mission as a countermeasure for preventing further contamination or disease (e.g., bacterial, viral, or fungal typing in real-time)? **[ISS 1, Lunar 1, Mars 1]**
10b	Does the spacecraft environment exert selective pressure on microorganisms that presents the crew with increased health risks (e.g., Helicobacter and ulcers)? **[ISS 1, Lunar 1, Mars 1]**
10c	Does space flight alter microbial growth rates, mutation rates, or pathogenicity? **[ISS 1, Lunar 1, Mars 1]**
10d	Does space flight alter the exchange of genetic material between microorganisms? **[ISS 1, Lunar 1, Mars 1]**
10e	Does space flight alter host:microbe balance? **[ISS 1, Lunar 1, Mars 1]**
10f	Do microorganisms associated with biological life support systems or biological waste treatment systems enter the general spacecraft environment with consequent increase in health risks? **[ISS 3, Lunar 1, Mars 1]**

Related Risks :	**Environmental Health** Define Acceptable Limits for Contaminants in Air and Water **Immunology & Infection** Immune Dysfunction, Allergies and Autoimmunity Interaction of Space flight Factors, Infections and Malignancy **Clinical Capabilities** Monitoring and Prevention **Radiation** Acute Radiation Risks **Advanced Environmental Monitoring & Control** Monitor Surfaces, Food, and Soil **Advanced Life Support** Manage Waste
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Risk Title: Reduced Muscle Mass, Strength, and Endurance

Crosscutting Area :	Human Health and Countermeasures (HHC)
Discipline :	Skeletal Muscle Alterations
Risk Number :	11
Risk Description :	Performance of mission related physical activities may be impaired due to loss of muscle mass, strength, and endurance associated with prolonged exposure to hypogravity.
Context / Risk Factors :	Decreased loading of skeletal muscle during space flight is associated with decreased muscle size, reduced muscle endurance, and loss of muscle strength. The risk may be influence by sensory-motor deficits, contractile protein loss, changes in contractile phenotype, reduced oxidative capacity, bone loss, poor nutrition, or insufficient exercise.
Justification / Rationale :	There is a growing database demonstrating that skeletal muscles, particularly postural muscles of the lower limb, undergo atrophy and undergo structural and metabolic alterations during space flight. These alterations, if unabated, may affect performance of mission tasks. Exercise countermeasures have to-date not fully protected muscle integrity. ISS experience will guide countermeasure strategies for Mars missions.
Risk Rating :	**ISS:** Priority 2 **Lunar:** Priority 3 **Mars:** Priority 2
Current Countermeasures :	• Cycle ergometer • Moderate resistance exercise • Treadmill
Projected Countermeasures or Mitigations & other Deliverables:	• Artificial gravity (e.g., centrifuge with exercise capabilities) [TRL 3] • New programs of heavy resistance exercise (e.g., expanded exercise and loading capabilities) and/or biophysical interventions [TRL 6] • Pharmacological interventions [TRL 2]

	• Biophysical interventions [TRL 4] • New/improved programs of endurance exercise [TRL 6] • Nutritional interventions [TRL 6]
Research & Technology Questions [With Mission Priority]:	(see table below)

No.	Question
	Global/Systemic
11a	Can any one or combination of non-invasive modalities (exercise regimens, artificial gravity, etc.) protect or build skeletal muscle mass or maintain skeletal muscle strength or preserve skeletal muscle endurance during an ISS, lunar, or Mars mission? **[ISS 1, Lunar 1, Mars 1]**
11b	Can non-invasive countermeasures (resistive exercise, artificial gravity, etc.) aimed at counteracting atrophy processes during an ISS, lunar, or Mars mission maintain those deficits in skeletal muscle strength that appear to occur independently of the atrophy process? **[ISS 1, Lunar 1, Mars 1]**
11c	What combination of non-invasive modalities (exercise regimens, etc.), nutritional and micronutrient supplements, and hormonal or pharmacological interventions is most effective and efficient in protecting or increasing skeletal muscle mass, strength, and endurance prior to or during space flight? **[ISS 1, Lunar 1, Mars 1]**
11d	What hardware and/or technology is/are reliable and effective in preserving skeletal muscle mass, strength, and endurance during an ISS, lunar, or Mars mission? **[ISS 3, Lunar 3, Mars 3]**
11e	What technologies (e.g., ultrasound) can be used to monitor and quantify changes in skeletal muscle size, strength, and endurance during space flight? **[ISS 3, Lunar 3, Mars 3]**
11f	Does atrophy of the spinal musculature contribute to lower back pain in crewmembers during space flight or upon returning from an ISS, lunar, or Mars mission? **[ISS 3, Lunar 3, Mars 3]**
11g	What are the effects of skeletal muscle atrophy on whole body metabolism (e.g., insulin and glucose tolerance) during space flight? **[ISS 1, Lunar 3, Mars 1]**
11h	What are the effects of skeletal muscle atrophy on thermoregulation during space flight? **[ISS 3, Lunar 3, Mars 3]**
11i	What assistance devices/technologies can compensate for losses in skeletal muscle strength and endurance during space flight? **[ISS 3, Lunar 3, Mars 3]**
11j	Is the skeletal muscle atrophy, loss in skeletal muscle strength, and reduction in skeletal muscle endurance that occurs during an ISS, lunar, or Mars mission completely reversible upon return to Earth? **[ISS 3, Lunar 3, Mars 3]**
11k	What prescription modality(ies) (exercise regimens, physical therapy, etc.) facilitate recovery of skeletal muscle mass, strength, and endurance in crewmembers returning from an ISS, lunar, or Mars mission? **[ISS 1, Lunar 1, Mars 1]**
	Nutrition
11l	What are the nutritional and micronutrient requirements to maintain skeletal muscle mass during ISS, lunar, or Mars missions? (See also 16g and 16h) **[ISS 3, Lunar 3, Mars 3]**
	Skeletal Muscle/Cellular
11m	What cellular processes/signaling pathways (e.g. protein turnover) in skeletal muscle can be identified and targeted (pharmacological, gene therapy, hormones, etc.) to prevent or attenuate fiber atrophy, loss of skeletal muscle strength, and reductions in skeletal muscle endurance during ISS, lunar, or Mars missions? **[ISS 3, Lunar 3, Mars 3]**
11n	Is the capacity of skeletal muscle to grow or regenerate (satellite cells) compromised during or after a mission because of space flight conditions (e.g., radiation exposure, reduced skeletal muscle tension)? **[ISS 3, Lunar 2, Mars 1]**
	Cardiovascular

	11o	Does skeletal muscle atrophy of the lower extremity musculature (i.e. muscle pump) affect cardiovascular function (e.g., orthostatic hypotension) during an ISS, lunar, or Mars mission? **[ISS 1, Lunar 1, Mars 1]**
		Bone/Tendon
	11p	Does site-specific skeletal muscle atrophy contribute to the accelerated rate of bone loss in the central and peripheral skeleton because of countermeasures targeting select muscle groups and/or reduced forces at the tendon insertion sites during space flight? **[ISS 1, Lunar 2, Mars 1]**
	11q	What are the temporal relationships between the changes in structure and function of the bone, tendon, skeletal muscle, skeletal muscle-tendon interface, and skeletal muscle -bone interactions during space flight? **[ISS 2, Lunar 2, Mars 2]**
	11r	How does the atrophy process affect the structural and functional properties of connective tissue (tendons), the fiber-tendon interface and the tendon-bone interface during space flight? **[ISS 2, Lunar 2, Mars 2]**
		Sensory-Motor
	11s	How do the deficits in skeletal muscle mass associated with space flight affect the structural/functional properties of the sensory system and motor nerves? **[ISS 1, Lunar 1, Mars 1]**
	11t	To what extent do alterations in the sensory-motor system contribute to deficits in skeletal muscle strength and endurance during space flight? **[ISS 3, Lunar 3, Mars 3]**
Related Risks :		**Bone Loss**
		Accelerated Bone Loss and Fracture Risk
		Impaired Fracture Healing
		Injury to Joints and Intervertebral Structures
		Cardiovascular Alterations
		Occurrence of Serious Cardiac Dysrhythmias
		Diminished Cardiac and Vascular Function
		Skeletal Muscle Alterations
		Increased Susceptibility to Muscle Damage
		Sensory-Motor Adaptation
		Impaired Sensory-Motor Capability to Perform Operational Tasks During Flight, Entry, and Landing
		Impaired Sensory-Motor Capability to Perform Operational Tasks After Landing and Throughout Re-Adaptation
		Nutrition
		Inadequate Nutrition
		Clinical Capabilities
		Monitoring and Prevention
		Pharmacology of Space Medicine Delivery
		Ambulatory Care
		Rehabilitation on Mars
		Radiation
		Chronic and Degenerative Tissue Risks
		Advanced Food Technology
		Maintain Food Quantity and Quality

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Risk Title: Increased Susceptibility to Muscle Damage

Crosscutting Area :	Human Health and Countermeasures (HHC)
Discipline :	Skeletal Muscle Alterations

Risk Number :	12
Risk Description :	Risk of injury to skeletal muscle and associated connective tissues may be increased due to remodeling and weakening associated with prolonged exposure to hypogravity.
Context / Risk Factors :	Decreased loading of the musculoskeletal system during space flight is associated with skeletal muscle atrophy, changes in structural proteins, and remodeling of associated connective tissues (i.e., intramuscular, skeletal muscle tendon interface, etc.). This risk may be influenced by neural factors, oxidative capacity, nutrition, or exercise.
Justification / Rationale :	Skeletal muscle and associated connective tissue remodeling and weakening that result from hypogravity exposure lead to a greater likelihood of sustaining skeletal muscle and/or connective tissue damage and soreness ,which could result in an inability or reduced ability to perform mission-directed activities. The risk will increase with mission duration.
Risk Rating :	**ISS:** Priority 3 **Lunar:** Priority 3 **Mars:** Priority 2
Current Countermeasures :	• Cycle ergometer • Moderate resistance exercise • Treadmill • Conditioning
Projected Countermeasures or Mitigations & other Deliverables:	• Artificial gravity (e.g., centrifuge with exercise capabilities) [TRL 3] • New programs of heavy resistance exercise (e.g., expanded exercise and loading capabilities) and/or biophysical interventions [TRL 6] • Pharmacological interventions [TRL 2]
Research & Technology Questions [With Mission Priority]:	

No.	Question
12a	What prescription guidelines and compliance factors facilitate increased resistance to skeletal muscle and associated connective tissue injury in crewmembers prior to space flight? **[ISS 3, Lunar 3, Mars 3]**
12b	What hardware and/or technology is/are effective in preserving muscle structure during an ISS mission? **[ISS 3, Lunar N/A, Mars N/A]**
12c	What hardware and/or technology is/are effective in preserving muscle structure during a lunar mission? **[ISS N/A, Lunar 3, Mars N/A]**
12d	What hardware and/or technology is/are effective in preserving muscle structure during a Mars mission? **[ISS N/A, Lunar N/A, Mars 3]**
12e	Do countermeasure paradigms that counteract skeletal muscle atrophy processes during an ISS mission improve the structure-function properties of connective tissue systems? **[ISS 2, Lunar N/A, Mars N/A]**
12f	Do countermeasure paradigms that counteract skeletal muscle atrophy processes during a lunar mission improve the structure-function properties of connective tissue systems? **[ISS N/A, Lunar 2, Mars N/A]**
12g	Do countermeasure paradigms that counteract skeletal muscle atrophy processes during a Mars mission improve the structure-function properties of connective tissue systems? **[ISS N/A, Lunar N/A, Mars 2]**
12h	Do countermeasures that minimize atrophy processes and strengthen skeletal muscle tendon properties that are performed in states of unloading prevent injury from occurring during a mission and upon return to weight bearing states (e.g., 1-G)? **[ISS 1, Lunar 1, Mars 1]**
12i	What are the prescription guidelines and compliance factors needed for countermeasures (exercise, AG, etc.) during space flight to minimize susceptibility to skeletal muscle damage? **[ISS 1, Lunar 1, Mars 1]**

	12j	If a skeletal muscle injury occurs during space flight, what hardware and/or technology (e.g., strength measurement, muscle/connective tissue damage marker(s), pain surveys, diagnostic ultrasound) can be used to determine when it is safe for a crewmember to resume exercise or perform dynamic activities associated with the mission (e.g., EVA/exploration)? **[ISS 1, Lunar 1, Mars 1]**
	12k	What are the assistance devices/technologies that can compensate for a skeletal muscle and/or associated connective tissue injury during space flight? **[ISS 3, Lunar 3, Mars 3]**
	12l	What prescription guidelines and compliance factors facilitate injury-free skeletal muscle rehabilitation in crewmembers returning from an ISS mission? **[ISS 1, Lunar N/A, Mars N/A]**
	12m	What prescription guidelines and compliance factors facilitate injury-free skeletal muscle rehabilitation in crewmembers returning from a lunar mission? **[ISS N/A, Lunar 1, Mars N/A]**
	12n	What prescription guidelines and compliance factors facilitate injury-free skeletal muscle rehabilitation in crewmembers returning from a Mars mission? **[ISS N/A, Lunar N/A, Mars 1]**
Related Risks :		**Bone Loss**
		Accelerated Bone Loss and Fracture Risk
		Impaired Fracture Healing
		Injury to Joints and Intervertebral Structures
		Cardiovascular Alterations
		Occurrence of Serious Cardiac Dysrhythmias
		Diminished Cardiac and Vascular Function
		Skeletal Muscle Alterations
		Reduced Muscle Mass, Strength, and Endurance
		Clinical Capabilities
		Monitoring and Prevention
		Ambulatory Care
		Rehabilitation on Mars
		Radiation
		Chronic and Degenerative Tissue Risks
Important References :		Adams GR, Caiozzo VJ, Baldwin KM. Skeletal muscle unweighting: spaceflight and ground-based models. J Appl Physiol. 95:2185-201, 2003. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=14600160
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Risk Title: Impaired Sensory-Motor Capability to Perform Operational Tasks During Flight, Entry, and Landing

Crosscutting Area :	Human Health and Countermeasures (HHC)
Discipline :	Sensory-Motor Adaptation
Risk Number :	13
Risk Description :	Operational performance may be impaired by spatial disorientation, perceptual illusions, and/or disequilibrium which may occur during and after g-transitions due to maladaptation of the sensory-motor systems to the new gravito-inertial environment.
Context / Risk Factors :	This risk may be exacerbated by vehicle/habitat designs that do not maintain consistent architectural frames of reference or those presenting ambiguous visual orientation cues. It may also be exacerbated by low visibility situations (smoke, landing weather, poor lighting), environmental vibration, or unstable support surfaces (floors, seats).

Justification / Rationale :	Transitions between gravitational and dynamic acceleration environments are associated with sensory-motor adaptation mechanisms and potential adverse sensory conflict reactions. These may be problematic during periods requiring crew control of vehicles or other complex systems. These mechanisms and reactions are expressed with a high degree of individual variability due to crew training, crew experience, and other factors not well understood. Crew performance of routine and critical actions during launch, landing, and the periods immediately following these events may be compromised.
Risk Rating :	**ISS:** Priority 2 **Lunar:** Priority 2 **Mars:** Priority 2
Current Countermeasures :	**Landing** • Heads Up Display • Education and Training **In-Flight** • Vehicle architecture and layout to establish a sense of artificial vertical for individual modules (luminous exit placards to mark emergency egress paths, rack orientation and module layout, surface labels) • Preflight education and training in module simulators • EVA training in neutral buoyancy • Virtual reality techniques
Projected Countermeasures or Mitigations & other Deliverables:	• Auto-land capability on lunar or Mars landing and return vehicles [Lunar] [Mars] • Determine efficacy of re-adaptation head movements during entry [CRL 2] • Improved standards for workstation and spacecraft interior architecture [CRL 4] • Improved teleoperator displays [CRL 2] • Pre-flight or in-flight g- specific pre-adaptation techniques, (e.g., artificial gravity) [CRL 2] [Lunar] [Mars] • Pre-flight visual orientation training for IVA activities using VR techniques[CRL 2-5] • Preflight training, including high fidelity simulators [CRL 2] [Lunar] [Mars] • Spatial ability tests should be developed and validated to predict and improve individual performance [CRL 2] • Evaluate in-flight landing rehearsal simulators [CRL 2]
Research & Technology Questions [With Mission Priority]:	See table below

No.	Question
13a	What are the physiological bases for spatial disorientation, perceptual illusions, and vertigo? **[ISS 1, Lunar 1, Mars 1]**
13b	What combinations of visual, vestibular, and haptic cues cause spatial disorientation, perceptual illusions, and vertigo during and after g-transitions? **[ISS 2, Lunar 2, Mars 2]**
13c	Can g-transition-related spatial disorientation, perceptual illusions, and vertigo be predicted from mathematical models? **[ISS 3, Lunar 3, Mars 3]**
13d	What individual physiological and behavioral characteristics contribute to the large inter-individual differences in neurovestibular symptoms and signs? **[ISS 1, Lunar 1, Mars 1]**
13e	What individual physiological and behavioral characteristics will best predict susceptibility and adaptability? **[ISS 3, Lunar 3, Mars 3]**

	13f	What is the physiological basis for context-specific-adaptation? **[ISS 1, Lunar 1, Mars 1]**
	13g	To what extent can neurovestibular adaptation to weightlessness and/or artificial gravity take place in context-specific fashion, so crewmembers can be adapted to multiple environments and switch between them without suffering disorientation or motion sickness? **[ISS 2, Lunar 2, Mars 2]**
	13h	What preflight training techniques (e.g., virtual reality simulations, parabolic flight) can be used to alleviate the risks of spatial disorientation, perceptual illusions, and vertigo as astronauts launch, enter, and adapt to 0-G? **[ISS 2, Lunar 2, Mars 2]**
	13i	What in-flight training techniques (e.g., virtual reality simulations, treadmill with vibration isolation system, artificial gravity) can be used to alleviate the risks of vertigo, disorientation, and perceptual illusions as astronauts land and (re)adapt to Earth, Moon, or Mars gravity? **[ISS 3, Lunar 3, Mars 3]**
	13j	Is adaptation to the lunar gravity environment sufficient to reduce incidence of landing vertigo upon return to Earth? **[ISS N/A, Lunar 3, Mars N/A]**
	13k	What artificial gravity exposure regimens (g-level, angular velocity, duration, and repetition) will ameliorate the physiological and vestibular deconditioning associated with hypogravity during transit phases of a mission in order to increase the capability to perform operational tasks during flight, entry and landing? **[ISS N/A, Lunar 5, Mars 5]**
	13l	What level of supervisory control will mitigate the landing vertigo risk in landing on the Moon, Mars, and Earth? **[ISS 4, Lunar 4, Mars 4]**

Related Risks :	**Bone Loss**
	Accelerated Bone Loss and Fracture Risk
	Impaired Fracture Healing
	Injury to Joints and Intervertebral Structures
	Renal Stone Formation
	Cardiovascular Alterations
	Occurrence of Serious Cardiac Dysrhythmias
	Diminished Cardiac and Vascular Function
	Skeletal Muscle Alterations
	Reduced Muscle Mass, Strength, and Endurance
	Increased Susceptibility to Muscle Damage
	Sensory-Motor Adaptation
	Impaired Sensory-Motor Capability to Perform Operational Tasks After Landing and Throughout Re-Adaptation
	Motion Sickness
	Clinical Capabilities
	Monitoring and Prevention
	Ambulatory Care
	Rehabilitation on Mars
	Behavioral Health & Performance and Space Human Factors (Cognitive)
	Human Performance Failure Due to Neurobehavioral Problems
	Mismatch between Crew Cognitive Capabilities and Task Demands
	Radiation
	Acute and Late CNS Risks
	Space Human Factors Engineering

	Mismatch Between Crew Physical Capabilities and Task Demands
Important References :	Guedry FE and AJ Benson. Coriolis cross-coupling effects: Disorienting and nauseogenic or not? Aviation, Space, and Environmental Medicine. 49(1): 29-35, 1978. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=304719
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Risk Title: Impaired Sensory-Motor Capability to Perform Operational Tasks After Landing and Throughout Re-Adaptation

Crosscutting Area :	Human Health and Countermeasures (HHC)
Discipline :	Sensory-Motor Adaptation
Risk Number :	14
Risk Description :	Capability to egress the vehicle in an emergency or to perform post landing tasks may be compromised by impaired movement and coordination caused by long-term exposure to microgravity.
Context / Risk Factors :	This risk may be exacerbated by duration of microgravity exposure, cardiovascular deconditioning, muscle atrophy, orthostatic intolerance, relative hypovolemia, diminished aerobic capacity, and/or poor task, equipment or vehicle/habitat design.
Justification / Rationale :	Following prolonged microgravity exposure, several deconditioned physiological systems must readapt. Crewmembers may be unable to accomplish certain postflight physical activities involving upright posture, locomotion, and handling loads. Current methods of postflight rehabilitation may not be optimal to restore sensory-motor function.
Risk Rating :	**ISS:** Priority 2 **Lunar:** Priority 2 **Mars:** Priority 2
Current Countermeasures :	• Quantitative post-flight tests of spontaneous, positional and positioning nystagmus, postural stability, dynamic visual acuity, and gait [TRL/CRL 8] • Traditional clinical rehabilitation techniques

Projected Countermeasures or Mitigations & other Deliverables:	• Balance prostheses (e.g., tactile vest) [TRL/CRL6] • g-specific pre-adaptation for Mars landing (e.g., short radius intermittent or large radius continuous artificial gravity) and return to Earth [CRL 2] [Mars] • General or g-specific pre-adaptation techniques, (e.g., in-flight or pre-flight artificial gravity; sensory-motor generalization training techniques [CRL 2] • Improved EVA suits designed to mechanically mitigate fracture risk in the event of falls [TRL 2] [Mars] • Pre-flight or in-flight g- specific pre-adaptation techniques, (e.g., artificial gravity) [CRL2, TRL1] [Lunar] • Quantitative post-flight tests of gaze stability, and locomotion and corner turning stability [TRL 6, CRL 6]
Research & Technology Questions [With Mission Priority]:	

No.	Question
14a	What are the physiological bases for disruption of balance, locomotion, and eye-head coordination following g-transitions? **[ISS 1, Lunar 1, Mars 1]**
14b	Can disruption of balance, locomotion, and eye-head coordination following g-transitions be predicted from mathematical models? **[ISS 3, Lunar 3, Mars 3]**
14c	What individual physiological and behavioral characteristics contribute to the large inter-individual differences in neurovestibular symptoms and signs? **[ISS 1, Lunar 1, Mars 1]**
14d	What individual physiological and behavioral characteristics will best predict susceptibility and adaptability? **[ISS 3, Lunar 3, Mars 3]**
14e	What is the physiological basis for context-specific-adaptation? **[ISS 1, Lunar 1, Mars 1]**
14f	How can voluntary head movements during entry and landing be used to accelerate re-adaptation? **[ISS 3, Lunar 3, Mars 3]**
14g	What in-flight training techniques (e.g., virtual reality simulations, treadmill with vibration isolation system, artificial gravity) can be used to alleviate the risks of impaired balance control and movement coordination as astronauts land and (re)adapt to Earth, Moon, or Mars gravity? **[ISS 3, Lunar 3, Mars 3]**
14h	Is adaptation to the lunar gravity environment sufficient to reduce incidence of sensory-motor balance and coordination problems upon return to Earth? **[ISS N/A, Lunar TBD, Mars N/A]**
14i	What artificial gravity exposure regimens (g-level, angular velocity, duration, and repetition) will ameliorate the physiological and vestibular deconditioning associated with hypogravity during surface operation phases of a mission? **[ISS N/A, Lunar TBD, Mars TBD]**
14j	What artificial gravity exposure regimens (g-level, angular velocity, duration, and repetition) will ameliorate the physiological and vestibular deconditioning associated with hypogravity during transit phases of a mission in order to increase the capability to perform operational tasks after landing and throughout readaptation? **[ISS N/A, Lunar N/A, Mars TBD]**
14k	How can traditional clinical vestibular rehabilitation techniques be employed to usefully accelerate readaptation following g-transitions? **[ISS TBD, Lunar TBD, Mars TBD]**
14l	What objective assessment techniques can be used to determine crew readiness to return to normal activities following g-transitions? **[ISS TBD, Lunar TBD, Mars TBD]**

	<table><tr><td>14m</td><td>How can preflight or in-flight sensory-motor training or sensory aids improve post-landing postural and locomotor control and orthostatic tolerance? [ISS TBD, Lunar TBD, Mars TBD]</td></tr><tr><td>14n</td><td>To what extent can crewmembers "learn how to learn" by adapting to surrogate sensory-motor rearrangements? [ISS TBD, Lunar TBD, Mars TBD]</td></tr><tr><td>14o</td><td>What are the relative contributions of sensory-motor adaptation, neuromuscular deconditioning, and orthostatic intolerance to postflight neuro-motor coordination, ataxia, and locomotion difficulties? [ISS TBD, Lunar TBD, Mars TBD]</td></tr><tr><td>14p</td><td>What posture, locomotion, and gaze deficits result from transition to lunar gravity (1/6-G) or Mars gravity (3/8-G)? [ISS TBD, Lunar TBD, Mars TBD]</td></tr></table>
Related Risks :	**Bone Loss** Accelerated Bone Loss and Fracture Risk Impaired Fracture Healing Injury to Joints and Intervertebral Structures Renal Stone Formation **Cardiovascular Alterations** Occurrence of Serious Cardiac Dysrhythmias Diminished Cardiac and Vascular Function **Skeletal Muscle Alterations** Reduced Muscle Mass, Strength, and Endurance Increased Susceptibility to Muscle Damage **Sensory-Motor Adaptation** Impaired Sensory-Motor Capability to Perform Operational Tasks During Flight, Entry, and Landing Motion Sickness **Clinical Capabilities** Monitoring and Prevention Ambulatory Care Rehabilitation on Mars **Behavioral Health & Performance and Space Human Factors (Cognitive)** Human Performance Failure Due to Neurobehavioral Problems Mismatch between Crew Cognitive Capabilities and Task Demands **Radiation** Acute and Late CNS Risks **Space Human Factors Engineering** Mismatch Between Crew Physical Capabilities and Task Demands
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Risk Title: Motion Sickness

Crosscutting Area :	Human Health and Countermeasures (HHC)
Discipline :	Sensory-Motor Adaptation
Risk Number :	15
Risk Description :	Crew work capacity, vigilance, and motivation may be impaired by motion sickness symptoms occurring during and after g transitions.
Context / Risk Factors :	This risk is influenced by individual susceptibilities, spacecraft size and room available for movement. It does not appear to be correlated with susceptibility to terrestrial motion sickness. Symptoms are repeatable but often attenuated from flight to flight.
Justification / Rationale :	Space motion sickness (SMS) is a common component of human space flight. For Shuttle crews, 70% experience symptoms for the first 2-4 days in 0-g, with emesis occurring in 10-20%, and many experience similar symptoms for hours to days after landing. Several crewmembers have remained symptomatic during flight for up to two weeks. Current anti-motion sickness treatment with IM Promethazine is highly effective and allows nominal space flight operations in spite of the high incidence of SMS. However, this drug has potentially significant side effects that may further complicate acute adaptation to space flight and prevent regular prophylactic use. Readaptation motion sickness may occur during entry and landing, prompting similar symptoms and possible impairment. In both situations, head movements, which may be required for normal operations, may be provocative.
Risk Rating :	**ISS:** Priority 3 **Lunar:** Priority 3 **Mars:** Priority 3
Current Countermeasures :	• Oral Promethazine/Ephedrine • Oral Scopolamine/Dexedrine (rare) • IM Promethazine • Head and body movement restriction, heads-up-display (HUD) for landing
Projected Countermeasures or Mitigations & other Deliverables:	• New administration methods of medicines for rapid, reliable relief with fewer side effects [CRL 6]

- Techniques to quantify cognitive deficits as a side effect of medication [CRL 6]
- Technique for providing a form of stroboscopic vision to reduce incidence of motion sickness [CRL 4]

Research & Technology Questions [With Mission Priority]:

No.	Question
15a	What are the physiological mechanisms that trigger vomiting in space motion sickness? **[ISS 1, Lunar 1, Mars 1]**
15b	What is the physiological basis of the emetic linkage between vestibular and emetic centers? **[ISS 2, Lunar 2, Mars 2]**
15c	What individual physiological and behavioral characteristics contribute to the large inter-individual differences in neurovestibular symptoms and signs? **[ISS 1, Lunar 1, Mars 1]**
15d	What individual physiological and behavioral characteristics will best predict susceptibility and adaptability? **[ISS 3, Lunar 3, Mars 3]**
15e	What is the physiological basis for context-specific-adaptation? **[ISS 1, Lunar 1, Mars 1]**
15f	To what extent can neurovestibular adaptation to weightlessness and/or artificial gravity take place in context-specific fashion, so crewmembers can be adapted to multiple environments and switch between them without suffering disorientation or motion sickness? **[ISS 3, Lunar 3, Mars 3]**
15g	What preflight training techniques (e.g., virtual reality simulations, parabolic flight) can be used to alleviate the risks of space motion sickness? **[ISS 4, Lunar 4, Mars 4]**
15h	What in-flight training techniques (e.g., virtual reality simulations, treadmill with vibration isolation system, artificial gravity) can be used to alleviate the risks of space motion sickness as astronauts land and (re)adapt to Earth, Moon, or Mars gravity? **[ISS 4, Lunar 4, Mars 4]**
15i	Is adaptation to the lunar gravity environment sufficient to reduce incidence of motion sickness upon return to Earth? **[ISS N/A, Lunar 4, Mars N/A]**
15j	How does susceptibility to motion sickness due to Coriolis forces and cross-coupled canal stimuli vary as a function of g-levels between 0-G and 1-G, and also on RPM, radius, and head orientation during AG? **[ISS N/A, Lunar 1, Mars 1]**
15k	What are the best methods for quantifying the symptoms and signs of motion sickness and associated performance decrements and drug side effects in a non-intrusive way? **[ISS 2, Lunar 2, Mars 2]**
15l	What better ways can be found to administer anti-motion sickness drugs to provide more rapid and reliable relief, with fewer objectionable side effects? **[ISS 3, Lunar 3, Mars 3]**
15m	Do scopolamine and promethazine prevent or impair sensory-motor adaptation to 0-G? **[ISS 4, Lunar 4, Mars 4]**
15n	What new drugs will more specifically prevent nausea, fatigue, memory and vigilance deficits without side effects? **[ISS 4, Lunar 4, Mars 4]**
15o	Can drugs be developed to effectively block the emetic linkage without unacceptable side effects? **[ISS 4, Lunar 4, Mars 4]**
15p	Can operationally practical, non-pharmacologic techniques be developed that are effective against motion sickness? **[ISS 4, Lunar 4, Mars 4]**
15q	Is lunar gravity (1/6-G) or Mars gravity (3/8-G) adequate to prevent all cases of motion sickness? **[ISS 4, Lunar 4, Mars 4]**

Related Risks :

Sensory-Motor Adaptation
Impaired Sensory-Motor Capability to Perform Operational Tasks During Flight, Entry, and Landing

	Impaired Sensory-Motor Capability to Perform Operational Tasks After Landing and Throughout Re-Adaptation **Clinical Capabilities** Monitoring and Prevention Pharmacology of Space Medicine Delivery Ambulatory Care Rehabilitation on Mars **Behavioral Health & Performance and Space Human Factors (Cognitive)** Human Performance Failure Due to Poor Psychosocial Adaptation Human Performance Failure Due to Neurobehavioral Problems **Space Human Factors Engineering** Mismatch Between Crew Physical Capabilities and Task Demands
Important References :	Davis JR, JM Vanderploeg, et al. (1988) "Space motion sickness during 24 flights of the Space Shuttle." Aviat Space Environ. Med. 59: 1185-1189. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=3240221 Graybiel A, and Lackner JR. Treatment of severe motion sickness with antimotion sickness drug injections. Aviat Space and Environ Med. 58: 773-776, 1987. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=3632537 Guedry FE and AJ Benson. Coriolis cross-coupling effects: Disorienting and nauseogenic or not? Aviation, Space, and Environmental Medicine, 49(1): 29-35, 1978. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=304719 Lackner JR and Graybiel A. Head movements made in non-terrestrial force environments elicit motion sickness: implications for the etiology of space motion sickness. Aviat Space and Environ Med. 57: 443-448, 1986. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=3632537 Matsnev EI, IY Yakovleva, et al. (1983) "Space motion sickness: phenomenology, countermeasures, and mechanisms." Aviat Space and Environ Med. 54: 312-317. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=6847567 Baldwin, et. al. (1997) NASA Task Force on Countermeasures, Final Report. Neurovestibular Countermeasures Appendix E-26 Cowings PS. (1990) Autogenic-Feedback Training: A Preventive Method for Motion and Space Sickness. In: (G. Crampton (ed.). Motion and Space Sickness. Boca Raton Florida: CRC Press. Chapter 17, Pp.354-372 Oman CM, BK Lichtenberg et .al. (1990) Symptoms and signs of space motion sickness on Spacelab-1. Motion and Space Sickness. G. H. Crampton. Boca Raton, FL, CRC Press: 217-246. Reschke MF, JJ Bloomberg et al. (1994) Neurophysiological Aspects: Sensory and Sensory-Motor Function. Space Physiology and Medicine. A. E. Nicogossian, Lea and Febiger. Wood CD, Graybiel A. (1968). Evaluation of Sixteen Anti-motion Sickness Drugs Under Controlled Laboratory Conditions. Aerosp Med. 39:1341-4. Oman CM. (1990) "Motion sickness: a synthesis and evaluation of the sensory conflict theory." Can J Physiol Pharmacol. 68: 294-303.

Risk Title: Inadequate Nutrition

<table>
<tr><td>Crosscutting Area :</td><td>Human Health and Countermeasures (HHC)</td></tr>
<tr><td>Discipline :</td><td>Nutrition</td></tr>
<tr><td>Risk Number :</td><td>16</td></tr>
<tr><td>Risk Description :</td><td>Maintenance of astronaut health depends on a food system that provides all of the required nutrients.</td></tr>
<tr><td>Context / Risk Factors :</td><td>Nutritional requirements for space include fluids, macronutrients, micronutrients and other elements required to optimize health status. Requirements must take into account any changes in the sensory system that might influence taste, smell, intake, and the role that countermeasure- and space flight factor-induced alterations may have on nutrient requirements. This risk may be influenced by psychosocial factors, elevated stress and boredom, or compliance with diet.</td></tr>
<tr><td>Justification / Rationale :</td><td>Nutritional deficiencies may lead to an increased health risk as the duration of space flight increases. Inadequate micronutrient or vitamin intake could adversely affect crew health. Furthermore, adequate nutrition may play a role in counteracting the negative effects of space flight (e.g., radiation, immune deficits, and bone and muscle loss). While all long duration crewmembers have lost body mass, the cause of weight loss is not yet fully understood. For a Mars mission, there are additional challenges to provide a variety of fresh, palatable, and nutritious foods.</td></tr>
<tr><td>Risk Rating :</td><td>ISS: Priority 3
Lunar: Priority 3
Mars: Priority 2</td></tr>
<tr><td>Current Countermeasures :</td><td>• Provision of adequate diet through use of proper food system and vitamin supplements</td></tr>
<tr><td>Projected Countermeasures or Mitigations & other Deliverables:</td><td>• Improved dietary compliance and counseling [CRL 4]
• Enhanced food system [CRL 4]
• Diet and nutritional supplementation that ensures and/or enhances the effectiveness of other countermeasures [CRL 4]
• Refined nutritional requirements [CRL 4]
• Understanding and implementing an acceptable food system [CRL 4]</td></tr>
<tr><td>Research & Technology Questions [With Mission Priority]:</td><td>
<table>
<tr><th>No.</th><th>Question</th></tr>
<tr><td>16a</td><td>What are the nutritional requirements for extended stay ISS missions, including (but not limited to): calories, protein, calcium, iron, antioxidants, iodine, vitamin D, sodium, potassium? [ISS 1, Lunar 1, Mars 1]</td></tr>
<tr><td>16b</td><td>What are the potential impacts of countermeasures on nutritional requirements or nutritional status? [ISS 1, Lunar 1, Mars 1]</td></tr>
<tr><td>16c</td><td>What are the decrements in nutritional status due to long-term LEO, lunar, and exploration missions? [ISS 1, Lunar 1, Mars 1]</td></tr>
<tr><td>16d</td><td>What are the means of monitoring nutritional status during the mission? [ISS 3, Lunar 3, Mars 3]</td></tr>
<tr><td>16e</td><td>What monitoring (biochemical, anthropometric, clinical assessments) during rehabilitation is required? [ISS 3, Lunar 3, Mars 3]</td></tr>
<tr><td>16f</td><td>What level of dietary counseling is needed for crewmembers during rehabilitation? [ISS 3, Lunar 3, Mars 3]</td></tr>
<tr><td>16g</td><td>Can general nutrition, or specific nutrient countermeasures, mitigate the negative effects of space flight on bone, muscle, cardiovascular and immune systems, and protect against damage from radiation? [ISS 1, Lunar 1, Mars 1]</td></tr>
<tr><td>16h</td><td>What is the role of adequate nutrition/weight maintenance on crew health (specifically bone, muscle and cardiovascular adaptation)? [ISS 1, Lunar 2, Mars 1]</td></tr>
<tr><td>16i</td><td>What level of dietary counseling is needed for crewmembers pre-flight? [ISS 1, Lunar 2, Mars 1]</td></tr>
</table>
</td></tr>
</table>

	16j	How does on-orbit exercise affect nutritional requirements and vice versa? **[ISS 1, Lunar 2, Mars 1]**
	16k	Can general nutrition, or specific nutrient countermeasures, mitigate radiation-induced carcinogenesis or cataractogenesis? **[ISS 1, Lunar 1, Mars 1]**
	16l	Are there long-term effects of disease risk post-flight, and can nutritional countermeasures be preventative? **[ISS 1, Lunar 2, Mars 1]**

Related Risks :	**Bone Loss**
	Accelerated Bone Loss and Fracture Risk
	Impaired Fracture Healing
	Renal Stone Formation
	Cardiovascular Alterations
	Occurrence of Serious Cardiac Dysrhythmias
	Diminished Cardiac and Vascular Function
	Immunology & Infection
	Immune Dysfunction, Allergies and Autoimmunity
	Interaction of Space flight Factors, Infections and Malignancy
	Skeletal Muscle Alterations
	Reduced Muscle Mass, Strength, and Endurance
	Increased Susceptibility to Muscle Damage
	Clinical Capabilities
	Monitoring and Prevention
	Major Illness and Trauma
	Pharmacology of Space Medicine Delivery
	Ambulatory Care
	Rehabilitation on Mars
	Behavioral Health & Performance and Space Human Factors (Cognitive)
	Human Performance Failure Due to Poor Psychosocial Adaptation
	Radiation
	Carcinogenesis
	Acute and Late CNS Risks
	Chronic and Degenerative Tissue Risks
	Acute Radiation Risks
	Advanced Food Technology
	Maintain Food Quantity and Quality
	Advanced Life Support
	Provide and Maintain Bioregenerative Life Support Systems
	Provide and Recover Potable Water
Important References :	NASA Johnson Space Center. Nutritional Requirements for International Space Station Missions Up To 360 Days. JSC-28038; 1996.
	Nutrition. 18:793-936, 2002. (volume dedicated to nutrition and space, >20 articles)

Risk Title: Monitoring and Prevention

Crosscutting Area :	Autonomous Medical Care (AMC)
Discipline :	Clinical Capabilities
Risk Number :	17
Risk Description :	The risk of serious medical events may increase due to inadequate monitoring and prevention capabilities.
Context / Risk Factors :	This risk may be influenced by family history, medical history, and pre-flight or pre-mission screening.
Justification / Rationale :	The primary means to reduce the risk of life- and/or mission-threatening medical conditions is to prevent those conditions from happening through screening and preventive strategies. The second most effective means to reduce such risk is to monitor for medical conditions so that treatment can be implemented at an early stage. Autonomous monitoring and care strategies need to be validated in low earth orbit where support is assured. Because of increased distance and delay in communication, the medical monitoring support for a lunar mission will transition from predominately ground based to an autonomous system. For a mission to Mars, due to distance, delay in communication and no return capability, real time monitoring and medical support will be exclusively autonomous.
Risk Rating :	**ISS:** Priority 2 **Lunar:** Priority 2 **Mars:** Priority 1
Current Countermeasures :	• Annual and preflight comprehensive physical exams • In-flight examination, monitoring and care • Selection standards for space flight
Projected Countermeasures or Mitigations & other Deliverables:	• Additional screening criteria • Better in flight health monitoring capability • A more autonomous, reliable suite of medical diagnostic and therapeutic clinical care hardware and procedures [Lunar] [Mars]
Research & Technology Questions [With Mission Priority]:	(see table below)

No.	Question
	Health Tracking
17a	What are the key parameters for health screening and early detection? **[ISS 4, Lunar 2, Mars 1]**
17b	What resources and technologies are required for routine health monitoring, including examination, laboratory, imaging and adaptation for operation in reduced-G environments? **[ISS 4, Lunar 2, Mars 1]**
17c	What diagnostic imaging technologies and procedures need to be developed and/or adapted to support the primary, secondary and tertiary prevention of illness and injury? **[ISS 3, Lunar 2, Mars 1]**
17d	What parameters and sensors are needed to monitor health and performance in crewmembers performing EVA? **[ISS 4, Lunar 2, Mars 2]**
17e	What are the investigations needed to discriminate between terrestrial and space flight norms in order to allow early detection of illness and injury? **[ISS 3, Lunar 2, Mars 2]**
17f	What is space-normal physiology? **[ISS 4, Lunar 3, Mars 3]**
17g	What are the signs, symptoms or abnormal examination findings (including laboratory) associated with illness and injury in reduced-G? **[ISS TBD, Lunar TBD, Mars TBD]**
17h	How do alterations in space flight associated physiology interact across body systems? **[ISS 4, Lunar 3, Mars 3]**
17i	What are the appropriate informatics tools to automate crew health monitoring in order to free-up crew time (i.e. prompting screening and evaluations, off-nominal value detection, intelligent diagnostic work-up)? **[ISS 2, Lunar 1, Mars 1]**
	Prophylaxis/Disease Prevention

	17j	What are the ideal set of nutritional and medical prophylaxes, and primary and secondary preventive measures to reduce the risk of space illness (such as medical countermeasures for known conditions - e.g., bisphosphonates for loss of BMD)? **[ISS 3, Lunar 2, Mars 2]**
	17k	What are the primary, secondary, and tertiary prevention strategies needed to mitigate the risk of anticipated environmental exposures to radiation and toxic substances (i.e. shielding, nutritional and medical prophylaxis such as agents to augment cellular defenses, immune surveillance, etc.)? **[ISS 2, Lunar 1, Mars 1]**
	17l	What are the essential technologies, resources, procedures, skills and training necessary to provide effective primary prevention strategies to mitigate each of the conditions listed in the SMCCB-approved Space Medicine Condition List (catalogued in the online Patient Condition Database)? **[ISS 4, Lunar 3, Mars 2]**
	17m	What are the essential technologies, resources, procedures, skills and training necessary to provide effective secondary prevention strategies to mitigate each of the conditions listed in the SMCCB-approved Space Medicine Condition List (catalogued in the online Patient Condition Database)? **[ISS 4, Lunar 3, Mars 2]**

Related Risks :	**Bone Loss**
	Accelerated Bone Loss and Fracture Risk
	Injury to Joints and Intervertebral Structures
	Renal Stone Formation
	Cardiovascular Alterations
	Occurrence of Serious Cardiac Dysrhythmias
	Diminished Cardiac and Vascular Function
	Environmental Health
	Define Acceptable Limits for Contaminants in Air and Water
	Immunology & Infection
	Immune Dysfunction, Allergies and Autoimmunity
	Interaction of Space flight Factors, Infections and Malignancy
	Alterations in Microbes and Host Interactions
	Skeletal Muscle Alterations
	Reduced Muscle Mass, Strength, and Endurance
	Increased Susceptibility to Muscle Damage
	Sensory-Motor Adaptation
	Impaired Sensory-Motor Capability to Perform Operational Tasks During Flight, Entry, and Landing
	Impaired Sensory-Motor Capability to Perform Operational Tasks After Landing and Throughout Re-Adaptation
	Motion Sickness
	Nutrition
	Inadequate Nutrition
	Clinical Capabilities
	Major Illness and Trauma
	Pharmacology of Space Medicine Delivery
	Ambulatory Care
	Rehabilitation on Mars
	Medical Informatics, Technologies, and Support Systems

	Medical Skill Training and Maintenance **Behavioral Health & Performance and Space Human Factors (Cognitive)** Human Performance Failure Due to Poor Psychosocial Adaptation Human Performance Failure Due to Neurobehavioral Problems Human Performance Failure Due to Sleep Loss and Circadian Rhythm Problems **Radiation** Acute and Late CNS Risks Chronic and Degenerative Tissue Risks Acute Radiation Risks **Advanced Environmental Monitoring & Control** Monitor Air Quality Monitor External Environment Monitor Water Quality Monitor Surfaces, Food, and Soil **Advanced Extravehicular Activity** Provide Space Suits and Portable Life Support Systems
Important References :	

Risk Title: Major Illness and Trauma

Crosscutting Area :	Autonomous Medical Care (AMC)
Discipline :	Clinical Capabilities
Risk Number :	18
Risk Description :	Lack of capability to treat major illness and injuries increases the risk to crew health and mission.
Context / Risk Factors :	Risk of trauma will vary according to mission activities and risk of illness will increase with mission duration. Equipment and activities are designed to minimize risk of injury.
Justification / Rationale :	For ISS, the risk for major trauma is considered low. For missions to the Moon and Mars, there is a significant risk of trauma associated with EVA. There is a risk for development of major illness.
Risk Rating :	**ISS:** Priority 2 **Lunar:** Priority 1 **Mars:** Priority 1
Current Countermeasures :	• Return to Earth for definitive care • On-board treatment capability (ventilator, IV fluids, medications, etc.) • Preventive measures
Projected Countermeasures or Mitigations & other Deliverables:	• Autonomous capabilities for monitoring and treatment of identified conditions, because quick return is not an option for missions to the Moon and Mars
Research & Technology Questions [With Mission Priority]:	

No.	Question
18a	What are the essential technologies, resources, procedures, skills, and training necessary to provide effective prevention strategies to mitigate each of the conditions listed in the SMCCB-approved Space Medicine Condition List (catalogued in the online Patient Condition Database)? **[ISS 3, Lunar 1, Mars 1]**
	Major Illness Diagnosis

	18b	What are the technologies for employing decision support techniques for diagnostic assistance of the crew medical personnel, emphasizing autonomy in decision-making from ground resources and based on known space flight illnesses and injuries and expedition analog experience? **[ISS 2, Lunar 1, Mars 1]**
	18c	What are the appropriate roles and resources required for telemedical consultation for the diagnosis and management of major illnesses? **[ISS 3, Lunar 2, Mars 1]**
	18d	What resources are required for telemedical consultation, diagnosis, and management of major trauma? **[ISS 3, Lunar 2, Mars 1]**
		Major Illness Treatment
	18e	What are the resources, procedures, and technologies required for treatment of major illnesses, emphasizing autonomy from ground resources and based on known space flight illnesses, injuries, and expedition analog experience, and how might they be adapted for reduced-G operations? **[ISS 2, Lunar 1, Mars 1]**
	18f	What are the resources and procedures needed to perform basic and advanced management of trauma? **[ISS 3, Lunar 1, Mars 1]**
	18g	What are the specific techniques, resources, protocols, training curricula, skills, and equipment (technology) necessary to implement palliative care protocols for in-flight use? **[ISS 4, Lunar 2, Mars 1]**
	18h	What are effective management strategies for chronic pain in reduced-G (pharmacologic and non-pharmacologic)? **[ISS TBD, Lunar TBD, Mars TBD]**
	18i	What procedures and protocols are necessary for rehabilitation after an acute medical illness or trauma? **[ISS 4, Lunar 3, Mars 1]**
	18j	What are effective management strategies for acute pain in reduced-G (pharmacologic and non-pharmacologic)? **[ISS TBD, Lunar TBD, Mars TBD]**
	18k	What are the nutritional requirements for adequate red cell production in microgravity? What are the contributory factors and how do they inter-relate in the development of space anemia (radiation, unloading, nutrition, fluid shift, changes in sex hormones, etc.)? **[ISS 2, Lunar 2, Mars 2]**
	18l	How can aplastic anemia be treated during space missions? **[ISS 5, Lunar 5, Mars 3]**
	18m	What are the appropriate synergistic and alternative management strategies for reducing the morbidity of major illnesses during space flight? **[ISS TBD, Lunar TBD, Mars TBD]**
	18n	What is the most effective means of conducting life support operations in the space flight milieu, to include identification and modification of the resources and procedures for reduced-G? **[ISS 3, Lunar 2, Mars 1]**
	18o	What are the optimal resources and procedures for post-resuscitation management of the ill/injured crewmember and modify for reduced-G operations? **[ISS 2, Lunar 1, Mars 1]**
		Decompression Illness (DCS) & Other Environmental Illness
	18p	What is the most effective pre-EVA Decompression Sickness (DCS) prevention strategy to include pre-breathe with various gases, exercise and other medical measures? **[ISS 5, Lunar TBD, Mars TBD]**
	18q	What are the appropriate screening procedures to minimize predispositions for DCS? **[ISS 4, Lunar TBD, Mars TBD]**
	18r	What are the resources and techniques for early diagnosis of DCS signs and symptoms, including the use of Doppler U/S and other bubble detection technologies? **[ISS 4, Lunar TBD, Mars TBD]**
	18s	What are the best methods for predicting DCS risk and for reducing the risk, based on understanding of the physiological mechanism for bubble formation and propagation, employing best available knowledge from flight and analog environment experience? **[ISS 4, Lunar TBD, Mars TBD]**

18t	What are the most effective yet safe, and energy- and space-efficient means of managing DCS in the space flight milieu, including the use of hyperbaric oxygen delivery and other promising technology, and how might they be adapted for reduced-G operations? **[ISS 3, Lunar 2, Mars 1]**
18u	What is the actual risk of space-related DCS? (de novo physiological causes and acute environmental insult - e.g., leaking module or damaged EMU etc.) **[ISS 3, Lunar 3, Mars 3]**
18v	What are the operational and medical impacts of off-nominal performance of DCS countermeasures? **[ISS 4, Lunar 3, Mars 3]**
18w	What are the risk factors that can increase the likelihood of DCS, such as the presence of Patent Foramen Ovale (PFO)? **[ISS 4, Lunar 3, Mars 2]**
18x	What is the likelihood of surviving an acute environmental insult severe enough to cause damage to the vehicle or spacesuit? **[ISS 2, Lunar 2, Mars 2]**
18y	Is it possible and what are the DCS risk mitigation options for interplanetary EVA (e.g., moon and Mars) given that a tri-gas breathing mixture including argon is present? **[ISS 4, Lunar 4, Mars 4]**
18z	What is the role of individual susceptibility, age and gender on the risk of DCS during NASA operations involving decompression? **[ISS 4, Lunar 3, Mars 3]**
18aa	What are the available and new technologies needed to provide hyperbaric treatment options on the ISS and future habitats (or vehicles) beyond LEO (e.g., on the moon or Mars)? **[ISS 3, Lunar 2, Mars 1]**
18ab	What is the correlation between the detection/existence of gas phase creation in the bloodstream and development of clinically significant DCS? **[ISS 4, Lunar 3, Mars 3]**
18ac	What are the monitoring, prevention, and treatment methods for clinical effects of acute, excessive, radiation exposure? **[ISS 3, Lunar 2, Mars 1]**
18ad	What are the signs and symptoms secondary to radiation and toxic chemical exposure in reduced-G environments? **[ISS 2, Lunar 1, Mars 1]**
18ae	What are the resources and procedures for the mitigation of toxic exposures? **[ISS 3, Lunar 1, Mars 1]**
18af	What primary prevention strategies (such as crew screening and selection criteria) should be developed and implemented to identify individuals who are at increased risk for developing hypersensitivity or allergies to space flight compounds, exposures, or payloads? **[ISS 3, Lunar 2, Mars 2]**
18ag	What secondary prevention strategies (i.e. countermeasures) should be developed and implemented to prevent adverse reactions to toxic exposures (e.g., sleep, nutrition, medication, stress reduction, shielding, protective equipment, etc.)? **[ISS 3, Lunar 2, Mars 2]**
Surgical Management	
18ah	What resources and procedures are needed for the surgical management of major illness, injury, and trauma? **[ISS 3, Lunar 1, Mars 1]**
18ai	What are the appropriate roles and resources required for telemedical consultation for the surgical management of major illnesses? **[ISS 3, Lunar 2, Mars 1]**
18aj	What are the issues surrounding wound care, and how are they best resolved? **[ISS 4, Lunar 2, Mars 2]**
18ak	What are effective regional and local anesthesia strategies in reduced G? **[ISS TBD, Lunar TBD, Mars TBD]**
18al	What methods and new technologies are needed for blood replacement therapy in space? **[ISS 3, Lunar 2, Mars 1]**
Medical Waste Management	
18am	What are the most effective means of management and disposal of medical waste within the surgical milieu? **[ISS 2, Lunar 1, Mars 1]**

Related Risks :	**Bone Loss**

	Accelerated Bone Loss and Fracture Risk Impaired Fracture Healing Renal Stone Formation **Cardiovascular Alterations** Occurrence of Serious Cardiac Dysrhythmias Diminished Cardiac and Vascular Function **Environmental Health** Define Acceptable Limits for Contaminants in Air and Water **Immunology & Infection** Immune Dysfunction, Allergies and Autoimmunity Interaction of Space flight Factors, Infections and Malignancy **Clinical Capabilities** Monitoring and Prevention Pharmacology of Space Medicine Delivery Ambulatory Care Rehabilitation on Mars Medical Informatics, Technologies, and Support Systems Medical Skill Training and Maintenance **Behavioral Health & Performance and Space Human Factors (Cognitive)** Human Performance Failure Due to Neurobehavioral Problems **Radiation** Carcinogenesis Acute and Late CNS Risks Chronic and Degenerative Tissue Risks Acute Radiation Risks **Advanced Extravehicular Activity** Provide Space Suits and Portable Life Support Systems
Important References :	

Risk Title: Pharmacology of Space Medicine Delivery

Crosscutting Area :	Autonomous Medical Care (AMC)
Discipline :	Clinical Capabilities
Risk Number :	19
Risk Description :	Diminished drug efficacy due to reduced shelf life and alterations in pharmacodynamics and pharmacokinetics may compromise treatment capabilities.
Context / Risk Factors :	Degraded shelf life may be related to the space radiation environment and other microgravity factors. This risk may be influenced by limited or no re-supply, microgravity, or the radiation environment.
Justification / Rationale :	Medications returned from ISS have been shown to have decreased potency beyond what is expected. Microgravity pharmacokinetics is not well understood.
Risk Rating :	**ISS:** Priority 2 **Lunar:** Priority 2 **Mars:** Priority 1
Current	

Countermeasures :	• Re-supply of medications on ISS
Projected Countermeasures or Mitigations & other Deliverables:	• Shielding of medications from space radiation • Alteration in dose and formulation of medication
Research & Technology Questions [With Mission Priority]:	

No.	Question
Pharmacodynamics/Pharmacokinetics	
19a	What are the effects of space flight and reduced-G on the absorption, distribution, metabolism, clearance, excretion, clinical efficacy, side effects and drug interactions for medications used in primary, secondary and tertiary prevention of conditions stated in the Space Medicine Condition List? **[ISS 2, Lunar 2, Mars 1]**
19b	How should the crew and medical team be trained and prepared to recognize and deal with side effects and interaction effects of commonly used medications? **[ISS 3, Lunar 3, Mars 2]**
19c	What diagnostic, therapeutic and laboratory technologies are necessary to predict (model) and manage medication side effects, interactions and toxicity during space flight? **[ISS 3, Lunar 3, Mars 3]**
19d	What effect does space adaptation have on drug bio-availability and how can efficacy be enhanced? **[ISS 2, Lunar 2, Mars 1]**
Drug Stowage/Utilization/Replenishment	
19e	What is the effect of long-duration space flight on drug stability, and what measures can be employed to extend the duration of drug efficacy? **[ISS 3, Lunar 1, Mars 1]**
19f	What are the appropriate on-orbit/on-station means of drug and intravenous (IV) fluid replenishment appropriate for space operations? **[ISS 3, Lunar 1, Mars 1]**
19g	What are biomedical models for drug efficacy? **[ISS 4, Lunar 3, Mars 3]**
Drug Use Optimization	
19h	What are the optimal dosages and routes of administration for space flight/reduced-G clinical effectiveness? **[ISS 3, Lunar 2, Mars 2]**
19i	What are efficient means of monitoring drug levels for therapeutic effect and toxicity to minimize cross-reaction and negative synergy? **[ISS 4, Lunar 3, Mars 3]**

Related Risks :

Bone Loss
Accelerated Bone Loss and Fracture Risk
Impaired Fracture Healing
Renal Stone Formation
Cardiovascular Alterations
Occurrence of Serious Cardiac Dysrhythmias
Diminished Cardiac and Vascular Function
Immunology & Infection
Immune Dysfunction, Allergies and Autoimmunity
Interaction of Space flight Factors, Infections and Malignancy
Skeletal Muscle Alterations
Reduced Muscle Mass, Strength, and Endurance
Sensory-Motor Adaptation
Motion Sickness
Clinical Capabilities
Monitoring and Prevention

	Major Illness and Trauma Ambulatory Care Rehabilitation on Mars Medical Informatics, Technologies, and Support Systems Medical Skill Training and Maintenance **Behavioral Health & Performance and Space Human Factors (Cognitive)** Human Performance Failure Due to Sleep Loss and Circadian Rhythm Problems **Radiation** Chronic and Degenerative Tissue Risks
Important References :	

Risk Title: Ambulatory Care

Crosscutting Area :	Autonomous Medical Care (AMC)
Discipline :	Clinical Capabilities
Risk Number :	20
Risk Description :	Impaired performance and increased risk to crew health and mission may occur due to lack of capability to diagnose and treat minor illnesses.
Context / Risk Factors :	Risks may vary depending on mission activities.
Justification / Rationale :	Minor illnesses and injuries have been documented during space flight. Capability to diagnose and treat minor medical conditions will ensure crew health remains good and the mission is not impacted. Current ISS capability is acceptable for future ISS missions
Risk Rating :	**ISS:** Priority 3 **Lunar:** Priority 3 **Mars:** Priority 2
Current Countermeasures :	• Crew Screening • Crew training to recognize and treat medical conditions • Design of equipment and procedures to reduce the likelihood of injury • Medical kits with capability to diagnose and treat minor illnesses and injuries • Limited telemedicine capability • Real-time ground communication with medical experts
Projected Countermeasures or Mitigations & other Deliverables:	• More extensive medical kit • More extensive telemedicine capability • On board autonomous medical diagnostic and therapeutic aids
Research & Technology Questions [With Mission Priority]:	

No.	Question
	Minor Illness Diagnosis
20a	What are the resources for establishing the diagnosis of minor illnesses, emphasizing autonomous decision-making, based on known space flight illnesses, injuries, and expedition analogs? How might they be adapted to reduced-G operations? **[ISS 4, Lunar 2, Mars 1]**
20b	What are the appropriate roles and resources required for telemedical consultation for the diagnosis and management of minor illnesses? **[ISS 4, Lunar 3, Mars 2]**
	Minor Illness Management

	<table><tr><td>20c</td><td>What are the resources and procedures required for treatment of minor illnesses, emphasizing autonomy from ground resources and based on known space flight illnesses and injuries and expedition analog experience, and how might they be adapted for reduced-G operations? [ISS 4, Lunar 3, Mars 2]</td></tr><tr><td>20d</td><td>What are the appropriate synergistic and alternative management strategies for reducing the morbidity of minor illnesses during space flight? [ISS TBD, Lunar TBD, Mars TBD]</td></tr><tr><td colspan="2">Minor Trauma Management</td></tr><tr><td>20e</td><td>What are the resources and procedures required for the treatment of minor trauma, emphasizing autonomous decision-making, based on known space flight illnesses, injuries, and expedition analogs? How might they be adapted to reduced-G operations? [ISS 3, Lunar 1, Mars 1]</td></tr></table>
Related Risks :	<table><tr><td>Bone Loss</td></tr><tr><td>Renal Stone Formation</td></tr><tr><td>Cardiovascular Alterations</td></tr><tr><td>Diminished Cardiac and Vascular Function</td></tr><tr><td>Immunology & Infection</td></tr><tr><td>Immune Dysfunction, Allergies and Autoimmunity</td></tr><tr><td>Interaction of Space flight Factors, Infections and Malignancy</td></tr><tr><td>Skeletal Muscle Alterations</td></tr><tr><td>Increased Susceptibility to Muscle Damage</td></tr><tr><td>Sensory-Motor Adaptation</td></tr><tr><td>Impaired Sensory-Motor Capability to Perform Operational Tasks During Flight, Entry, and Landing</td></tr><tr><td>Impaired Sensory-Motor Capability to Perform Operational Tasks After Landing and Throughout Re-Adaptation</td></tr><tr><td>Motion Sickness</td></tr><tr><td>Clinical Capabilities</td></tr><tr><td>Monitoring and Prevention</td></tr><tr><td>Major Illness and Trauma</td></tr><tr><td>Pharmacology of Space Medicine Delivery</td></tr><tr><td>Rehabilitation on Mars</td></tr><tr><td>Medical Informatics, Technologies, and Support Systems</td></tr><tr><td>Medical Skill Training and Maintenance</td></tr><tr><td>Behavioral Health & Performance and Space Human Factors (Cognitive)</td></tr><tr><td>Human Performance Failure Due to Poor Psychosocial Adaptation</td></tr><tr><td>Human Performance Failure Due to Neurobehavioral Problems</td></tr><tr><td>Human Performance Failure Due to Sleep Loss and Circadian Rhythm Problems</td></tr><tr><td>Advanced Extravehicular Activity</td></tr><tr><td>Provide Space Suits and Portable Life Support Systems</td></tr></table>
Important References :	

Risk Title: Rehabilitation on Mars

Crosscutting Area :	Autonomous Medical Care (AMC)

Discipline :	Clinical Capabilities
Risk Number :	21
Risk Description :	Crew capability to function after landing on Mars may be compromised due to space flight deconditioning and lack of a remote, self-administered, rehabilitation program.
Context / Risk Factors :	This risk may be influenced by sensory neural alterations and ability to autonomously perform exercise program. This assumes functioning exercise hardware.
Justification / Rationale :	This risk is unique to an exploration mission to Mars. Significant deconditioning can occur during the transit to Mars and the crew must be able to self-administer a rehabilitation program en route and once they arrive at Mars so that they can function as needed.
Risk Rating :	**ISS:** N/A **Lunar:** N/A **Mars:** Priority 1
Current Countermeasures :	• Ground rehabilitation program and facilities [Mars] • In flight exercise [Mars] • Pre-flight conditioning [Mars]
Projected Countermeasures or Mitigations & other Deliverables:	• Countermeasures to neurovestibular effects [Mars] • Improved exercise protocols [Mars] • Autonomous medical monitoring capability [Mars] • Structured, self-administered rehabilitation program (physical and psychological) [Mars]
Research & Technology Questions [With Mission Priority]:	(see table below)
Related Risks :	(see table below)

Research & Technology Questions [With Mission Priority]:

No.	Question
21a	What are the primary, secondary and tertiary preventive strategies needed to ensure post-landing performance for a Mars mission? **[ISS N/A, Lunar N/A, Mars 1]**
21b	What are the essential technologies, resources, protocols, skills and training necessary for post landing rehabilitation (including psychological, cardiovascular, neurosensory, musculoskeletal and nutritional)? **[ISS N/A, Lunar N/A, Mars 1]**

Related Risks :

Bone Loss
Accelerated Bone Loss and Fracture Risk
Impaired Fracture Healing
Injury to Joints and Intervertebral Structures
Renal Stone Formation
Cardiovascular Alterations
Occurrence of Serious Cardiac Dysrhythmias
Diminished Cardiac and Vascular Function
Immunology & Infection
Immune Dysfunction, Allergies and Autoimmunity
Interaction of Space flight Factors, Infections and Malignancy
Skeletal Muscle Alterations
Increased Susceptibility to Muscle Damage
Sensory-Motor Adaptation
Impaired Sensory-Motor Capability to Perform Operational Tasks During Flight, Entry, and Landing
Impaired Sensory-Motor Capability to Perform Operational Tasks After Landing and Throughout Re-Adaptation
Motion Sickness

	Nutrition Inadequate Nutrition **Clinical Capabilities** Monitoring and Prevention Major Illness and Trauma Pharmacology of Space Medicine Delivery Ambulatory Care Medical Informatics, Technologies, and Support Systems Medical Skill Training and Maintenance **Behavioral Health & Performance and Space Human Factors (Cognitive)** Human Performance Failure Due to Poor Psychosocial Adaptation Human Performance Failure Due to Neurobehavioral Problems Mismatch between Crew Cognitive Capabilities and Task Demands Human Performance Failure Due to Sleep Loss and Circadian Rhythm Problems **Radiation** Acute and Late CNS Risks Acute Radiation Risks
Important References :	

Risk Title: Medical Informatics, Technologies, and Support Systems

Crosscutting Area :	Autonomous Medical Care (AMC)
Discipline :	Clinical Capabilities
Risk Number :	22
Risk Description :	Limited communication capability during space flight results in the compromised ability to provide medical care, and may have adverse consequences for crew health.
Context / Risk Factors :	Risk will be exacerbated by lack of recent training, limited communication capability, and lack of real-time ground support.
Justification / Rationale :	Lack of real-time ground support due to limited communication and limited telemedical capability necessitates reliable, efficacious informatics capability and support. This is low priority for ISS, moderate priority for a lunar mission, and high priority for a Mars mission.
Risk Rating :	**ISS:** Priority 3 **Lunar:** Priority 2 **Mars:** Priority 1
Current Countermeasures :	• Limited telemedicine capability • On-board computer based training • Real-time ground support • Periodic on-orbit contingency drills • Medical checklist and preflight training
Projected Countermeasures or Mitigations & other Deliverables:	• Development of autonomous medical support systems

Research & Technology Questions [With Mission Priority]:	<table><tr><th>No.</th><th>Question</th></tr><tr><td>22a</td><td>What decision support technologies are needed to support clinical care? [ISS 4, Lunar 2, Mars 1]</td></tr><tr><td>22b</td><td>What informatics systems and technology are needed, both for crew and ground support, to optimize medical care? [ISS 3, Lunar 1, Mars 1]</td></tr><tr><td>22c</td><td>What are the impacts of communication latency on the ability to provide primary, secondary and tertiary prevention during space flight? [ISS 4, Lunar 4, Mars 1]</td></tr></table>
Related Risks :	<table><tr><td>Clinical Capabilities</td></tr><tr><td>Monitoring and Prevention</td></tr><tr><td>Major Illness and Trauma</td></tr><tr><td>Pharmacology of Space Medicine Delivery</td></tr><tr><td>Ambulatory Care</td></tr><tr><td>Rehabilitation on Mars</td></tr><tr><td>Medical Skill Training and Maintenance</td></tr><tr><td>Advanced Extravehicular Activity</td></tr><tr><td>Provide Space Suits and Portable Life Support Systems</td></tr><tr><td>Space Human Factors Engineering</td></tr><tr><td>Poorly Integrated Ground, Crew, and Automation Functions</td></tr></table>
Important References :	

Risk Title: Medical Skill Training and Maintenance

Crosscutting Area :	Autonomous Medical Care (AMC)
Discipline :	Clinical Capabilities
Risk Number :	23
Risk Description :	Inability to perform required medical procedures may result from inadequate crew medical skills or medical training.
Context / Risk Factors :	A physician may be required on a Mars crew.
Justification / Rationale :	Illness and injuries are likely to occur. The crew must be able to diagnose and treat a variety of conditions. Different mission scenarios will require a different level of expertise and autonomy. For ISS, real time ground support is available and there is return capability. For a lunar mission the crew must be trained more extensively because of reduced availability of ground support. The Mars crew will require extensive training and support hardware because of lack of ground support and return capability.
Risk Rating :	**ISS:** Priority 3 **Lunar:** Priority 2 **Mars:** Priority 1
Current Countermeasures :	• Limited telemedicine capability • On-board computer based training • Crew Medical Officer (CMO) training • Real-time ground support • Periodic on-orbit contingency drills
Projected Countermeasures or Mitigations & other	• More extensive medical training, including medical and surgical capabilities • Autonomous medical support systems

Deliverables:	
Research & Technology Questions [With Mission Priority]:	**No.** / **Question** 23a — What are the necessary clinical skills/knowledge for a space medicine physician? **[ISS 4, Lunar 1, Mars 1]** 23b — How can the clinical skills and knowledge of space medical care providers be maintained during missions? **[ISS 2, Lunar 2, Mars 1]** 23c — What is the optimum crew complement (size, skill sets, etc.) to provide the appropriate medical care for the primary, secondary and tertiary care for the conditions in the Space Medicine Condition List? **[ISS 4, Lunar 3, Mars 1]** 23d — What techniques can be used to train and maintain the skills of the crew medical personnel to perform specific medical procedures when needed? **[ISS 3, Lunar 1, Mars 1]**
Related Risks :	**Clinical Capabilities** Monitoring and Prevention Major Illness and Trauma Pharmacology of Space Medicine Delivery Ambulatory Care Rehabilitation on Mars Medical Informatics, Technologies, and Support Systems **Behavioral Health & Performance and Space Human Factors (Cognitive)** Mismatch between Crew Cognitive Capabilities and Task Demands **Space Human Factors Engineering** Poorly Integrated Ground, Crew, and Automation Functions
Important References :	

Risk Title: Human Performance Failure Due to Poor Psychosocial Adaptation

Crosscutting Area :	Behavioral Health and Performance (BHP)
Discipline :	Behavioral Health & Performance and Space Human Factors (Cognitive)
Risk Number :	24
Risk Description :	Human performance failure may occur due to problems associated with adapting to the space environment, interpersonal relationships, group dynamics, team cohesiveness, and pre-mission preparation.
Context / Risk Factors :	The isolated and confined nature of space flight, along with its potential hazards, pose human performance related challenges. This risk may be influenced by boredom with available food, crew autonomy and increased reliance on each other, crowding, distance from family and friends, duration of flight, incompatible crewmembers, interpersonal tensions, mechanical breakdowns, poor communications, scheduling constraints and requirements, sleep disturbances, or social isolation.
Justification / Rationale :	Moderate likelihood/high consequence risk with low risk mitigation status. Serious interpersonal conflicts have occurred in space flight. The failure of flight crews to cooperate and work effectively with each other or with flight controllers has been a periodic problem in both US and Russian space flight programs. Interpersonal distrust, dislike, misunderstanding and poor communication have led to potentially dangerous situations, such as crewmembers refusing to speak to one another during critical operations, or withdrawing from voice communications with ground controllers. Such problems of group cohesiveness have a high likelihood of occurrence in prolonged space flight and if not mitigated through prevention or intervention, they will pose grave risks to the mission. Lack of adequate personnel selection, team assembly, or training has been found to have deleterious effects on work performance in organizational research studies. The duration and distance of a Mars mission significantly increases this risk. The distance also reduces countermeasure options and increases the need for autonomous behavioral health support systems.

Risk Rating :	**ISS:** Priority 1 **Lunar:** Priority 2 **Mars:** Priority 1
Current Countermeasures :	• Language and cultural training, • Personal in-flight communications with Earth • Post-flight debriefs • Pre-flight training and teambuilding, • Self-report monitoring of adaptation during mission with private psychological conference • Select-out criteria • In-flight and preflight psychological support
Projected Countermeasures or Mitigations & other Deliverables:	• Development of individual performance enhancement plan for each crewmember [CRL 1] • Individual and team selection for long-duration missions [CRL 3] • Monitoring & early detection of adaptation problems [CRL 3] • Predictive model of adaptability to long-duration missions [CRL 1] • Select-in criteria
Research & Technology Questions [With Mission Priority]:	(see table below)

No.	Question
24a	What are the fundamental behavioral and social stressors during long-duration missions that will most likely affect crew performance, both individual and team, and how can they be studied for elimination or accomodation in Earth analogue environments? **[ISS 1, Lunar 1, Mars 1]**
24b	What factors contribute to the breakdown of individual/team performance and mission support coordination with regard to scheduling, prioritization of work activities, and control of timelines? **[ISS 1, Lunar 1, Mars 1]**
24c	What behaviors, experiences, personality traits and leadership styles in crewmembers most contribute to optimal performance? How are these factors related to performance of individuals and teams? **[ISS 2, Lunar 2, Mars 2]**
24d	What criteria can be identified during the selection process and be used to select and assemble the best teams for long-duration missions? **[ISS 2, Lunar 2, Mars 2]**
24e	What factors in crew design, composition, dynamics and size will best enhance the crew's ability to live and work in the space environment? How are these factors different from shorter duration missions? **[ISS 2, Lunar 2, Mars 2]**
24f	How can attitudes and behaviors of agency management, ground controllers, crewmembers and their families be modified to maintain and improve individual and group performance? **[ISS 2, Lunar 2, Mars 2]**

Related Risks :

Nutrition
Inadequate Nutrition
Clinical Capabilities
Monitoring and Prevention
Ambulatory Care
Behavioral Health & Performance and Space Human Factors (Cognitive)
Human Performance Failure Due to Neurobehavioral Problems
Mismatch between Crew Cognitive Capabilities and Task Demands
Human Performance Failure Due to Sleep Loss and Circadian Rhythm Problems
Radiation

	Acute and Late CNS Risks **Advanced Food Technology** Maintain Food Quantity and Quality **Space Human Factors Engineering** Poorly Integrated Ground, Crew, and Automation Functions
Important References :	Kanas N. Psychiatric issues affecting long-duration space missions. Aviation Space & Environmental Medicine. 69:1211-1216, 1998. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=9856550 McCormick IA, Taylor AJ, Rivolier J, & Cazes G. (1985). A psychometric study of stress and coping during the International Biomedical Expedition to the Antarctic (IBEA). J Human Stress. 11(4), 150-156. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=3843117 Palinkas LA, Gunderson EK, Holland AW, Miller C, & Johnson JC. (2000) Predictors of behavior and performance in extreme environments: the Antarctic space analogue program. Aviat Space Environ Med. 71(6): 619-625. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=10870821 Taylor AJ. (1998). Psychological adaptation to the polar environment. Int J Circumpolar Health. 57(1): 56-68. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=9567576 Wood JA, Hysong SJ, Lugg DJ, & Harm DL. (2000) Is it really so bad? A comparison of positive and negative experiences in Antarctic winter stations. Environment and Behavior. 32(1): 85-110. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=11542948 Wood JA, Lugg DJ, Hysong SJ, Eksuzian DJ, & Harm DL. (1999) Psychological changes in hundred-day remote Antarctic field groups. Environment and Behavior. 31(3): 299-337. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=11542387 Connors MM, Harrison AA, and Faren RA. Living Aloft: Human requirements for extended space flight. NASA SP-483, Washington, D.C., National Aeronautics and Space Administration, 1985. Harrison AA, Clearwater YA, and McKay CA. (eds), From Antarctica to outer space: Life in Isolation and Confinement. NY, NY Springer-Verlag, 1991. Palinkas LA. (1991) Effects of physical and social environments on the health and well-being of Antarctic winter-over personnel. Environment & Behavior. 23(6); 782-799. Palinkas LA, & Gunderson EK. (1988) Applied anthropology on the ice: A multidisciplinary perspective on health and adaptation in Antarctica (No. 88-21). San Diego: Naval Health Research Center.

Risk Title: Human Performance Failure Due to Neurobehavioral Problems

Crosscutting Area :	Behavioral Health and Performance (BHP)
Discipline :	Behavioral Health & Performance and Space Human Factors (Cognitive)
Risk Number :	25
Risk Description :	Human performance failure may occur due to conditions such as depression, anxiety, or other psychiatric and cognitive problems.

Context / Risk Factors :	For long duration missions, inadequate countermeasures or failure of early detection of behavioral health problems could result in more severe psychiatric problems. This risk may be influenced by clinical capabilities, concern about health or loss of life or mission failure, lack of privacy, differential vulnerability to neurobehavioral problems, duration of flight, environmental health, loneliness and worry about family, nutrition, prolonged isolation and confinement, or trauma from an unexpected event.
Justification / Rationale :	Although infrequent, serious neurobehavioral problems involving stress and depression have occurred in space flight, especially during long-duration missions. In some of these instances, the distress has contributed to performance errors. In other instances, emotional problems led to changes in motivation, diet, sleep and exercise-all critical to behavioral and physical health in-flight. No matter how prepared crews are for long-duration flights, the US and Russian experiences reveal that at least some subset of astronauts will experience problems with their behavioral health, which will negatively affect their performance and reliability, posing risks both to individual crewmembers and to the mission. The IOM report, Safe Passages, notes that Earth analogue studies show an incidence rate ranging from 3-13 percent per person per year. The report transposes these figures to 6-7 person crew on a 3-year mission to determine that there is a significant likelihood of psychiatric problems emerging (p.106).
Risk Rating :	**ISS:** Priority 1 **Lunar:** Priority 2 **Mars:** Priority 1
Current Countermeasures :	• Crew medical officer behavioral medicine training pre-flight • Detection at the time of failure • Emergency response protocol on-orbit • Individual pre-flight and post-flight evaluations • Medication therapy, including during space flight • Opportunity for crewmembers to communicate with crew medical officer or health provider on ground • Select-in and select-out criteria • Self monitoring of cognition on-orbit and post-flight • Self-report monitoring during mission with private psychological conference
Projected Countermeasures or Mitigations & other Deliverables:	• Greater interaction and observation by behavioral specialist during astronaut professional training [CRL 4] • Improved ability to safely and effectively manage an uncooperative crewmember during mission [CRL 3] • Improved capability for remote diagnosis [CRL 3] • Improved diagnostic cognitive self-assessment [CRL 3] • Individualized treatment algorithm developed pre-flight [CRL 5] • On-board information technologies as astronaut aids for management of stress reactions and cognitive or emotional problems [CRL 3] • On-board modalities of therapy [CRL 4] • On-board unobtrusive technologies as astronaut aids for valid detection of stress reactions and cognitive or emotional problems [CRL 3] • Predictive model for risk of neurobehavioral illness in-flight [CRL 3] • Self monitoring of mood pre-flight, in-flight and post-flight [CRL 4] • Updated behavioral medicine aeromedical standards [CRL 4]

Research & Technology Questions [With Mission Priority]:		
	No.	**Question**
	25a	What are the best select-out tools of astronaut candidates and best select-out tools for selection of individuals to teams for specific missions to avoid possible neuropsychiatric and psychological incompatibility with the mission and fellow team members? **[ISS 1, Lunar 1, Mars 1]**
	25b	What are the long-term effects of exposure to the space environment (microgravity, isolation, stress) on human neurocognitive and neurobiological functions (from cellular to behavioral levels of the nervous system)? **[ISS 2, Lunar 2, Mars 2]**
	25c	What are the long-term effects of exposure to the space environment on human emotion and psychological responses, including emotional reactivity, stress responses, long-term modulation of mood and vulnerability to affective and cognitive disorders? **[ISS 3, Lunar 3, Mars 3]**
	25d	What objective techniques and technologies validly and reliably identify when astronauts are experiencing distress that compromises their performance capability in space? **[ISS 1, Lunar 1, Mars 1]**
	25e	What are the best behavioral, technological and pharmacological countermeasures for managing cognitive dysfunction, neuropsychiatric and behavior problems in space? **[ISS 3, Lunar 3, Mars 3]**
	25f	What are the best behavioral, psychological, technological and pharmacological countermeasures for managing emotional and stress-related problems in space? **[ISS 3, Lunar 3, Mars 3]**
	25g	What are the best techniques and technologies for identification and treatment of cognitive disorders, neuropsychiatric and behavior problems in space? **[ISS 4, Lunar 4, Mars 4]**
	25h	What are the strategies for psychological stress management, and maintaining the morale and acceptable functioning and safety of remaining crewmembers after an adverse event during a mission? **[ISS 3, Lunar 1, Mars 1]**

Related Risks :	
	Sensory-Motor Adaptation
	Impaired Sensory-Motor Capability to Perform Operational Tasks During Flight, Entry, and Landing
	Impaired Sensory-Motor Capability to Perform Operational Tasks After Landing and Throughout Re-Adaptation
	Motion Sickness
	Clinical Capabilities
	Monitoring and Prevention
	Major Illness and Trauma
	Pharmacology of Space Medicine Delivery
	Ambulatory Care
	Rehabilitation on Mars
	Behavioral Health & Performance and Space Human Factors (Cognitive)
	Human Performance Failure Due to Poor Psychosocial Adaptation
	Mismatch between Crew Cognitive Capabilities and Task Demands
	Human Performance Failure Due to Sleep Loss and Circadian Rhythm Problems
	Radiation
	Acute and Late CNS Risks
	Acute Radiation Risks
	Advanced Food Technology
	Maintain Food Quantity and Quality
	Space Human Factors Engineering

	Poorly Integrated Ground, Crew, and Automation Functions
Important References :	Ellis SR. Collision in space. Ergonomics in Design. 8;4-9, 2000. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=12162316 Kanas N. Psychiatric issues affecting long-duration space missions. Aviation Space & Environmental Medicine. 69:1211-1216, 1998. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=9856550 Simpson S. Staying sane in space. Scientific American. 282:61-62, 2000. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=10736838 Burrough, B. Dragonfly: NASA and the crisis aboard Mir. NY, Harper Collins, 1998. Kanas N, Manzy D. Space Psychology and Psychiatry. El Segundo, CA, Microcosm Press, 2003. Linenger JM. Off the Planet. NY, McGraw Hill, 2000. Newkirk D. Almanac of Soviet Manned Space flight, Houston, TX, Gulf Publishing, 1990

Risk Title: Mismatch between Crew Cognitive Capabilities and Task Demands

Crosscutting Area :	Behavioral Health and Performance (BHP)
Discipline :	Behavioral Health & Performance and Space Human Factors (Cognitive)
Risk Number :	26
Risk Description :	Human performance failure may occur due to inadequate design of tools, interfaces, tasks, and information support systems. Task saturation may also occur due to compromises in crew health, human factors, and cognitive capabilities.
Context / Risk Factors :	The remote nature of space flight increases the likelihood and severity of consequences of error due to task saturation, losing skills and knowledge, or failing to find information and training materials in databases. Particularly on Moon and Mars missions, the distance and communication lags may require an autonomous response to any malfunction that may increase the incidence of performance error. This risk may be influenced by communication blackouts and lags, mission duration, required levels of autonomy, time since training, time since last performing a task, or level of support available from mission control on Earth.
Justification / Rationale :	Crews require refresher training and information support systems for numerous tasks during 6-month ISS missions (Evidence Level 4). Psychological literature documents increases in error with time since learning, and decreases in error with correctly practicing the task (Evidence level 1). Failure to correctly follow procedures has led to fatal accidents in commercial aviation, even with greatly over-learned tasks (NTSB Reports-Level 2)
Risk Rating :	**ISS:** Priority 2 **Lunar:** Priority 2 **Mars:** Priority 1
Current Countermeasures :	• Crew resilience is the countermeasure for schedule and interface problems • Mission Control provides training, information, and procedures as required to support crew actions and decision-making • Efforts by mission planners to maintain realistic workloads and schedules
Projected Countermeasures or Mitigations & other Deliverables:	• Design requirements for communications systems among crewmembers, between crew and mission control, and among crew and intelligent agents, that reduce risk of mission failure [TRL 2] • Onboard training systems that enable successful readiness to perform [TRL 2]

	• Tools for analyzing tasks to identify critical skills and knowledge [TRL 2] • Tools for enabling crew autonomy with respect to information retrieval [TRL 2] • Tools to enable self-assessment of readiness to perform [TRL 2]
Research & Technology Questions [With Mission Priority]:	

No.	Question
26a	What crew size and composition is required to provide the amount of information, variety of skills, etc. required to accomplish the reference mission? **[ISS 2, Lunar 1, Mars 1]**
26b	What is required to counteract the negative effects of communications lags on human performance? **[ISS 1, Lunar 1, Mars 1]**
26c	What information systems, interface designs, intelligent systems and other tools to enable autonomy are required to enable human performance to be maintained at an acceptable level over the reference missions? (Shared - Integrated Testing supports) **[ISS 2, Lunar 1, Mars 1]**
26d	What types and techniques of training are required and within what timeframes, to enable the crewmembers to accomplish the mission with increased effectiveness, efficiency and safety? **[ISS 1, Lunar 1, Mars 1]**
26e	What principles of task design, procedures, job aids and tools and equipment, are required to enable crewmembers to accomplish nominal and emergency perceptual and cognitive tasks? **[ISS 2, Lunar 1, Mars 1]**
26f	How can crewmembers and ground support personnel detect and compensate for decreased cognitive readiness to perform? **[ISS 1, Lunar 1, Mars 1]**
26g	What scheduling constraints are required to reduce the risk of human error due to fatigue? (shared with Sleep and Circadian Rhythm) **[ISS 2, Lunar 2, Mars 2]**
26h	What tools and techniques will maintain the crew's situational awareness at a level sufficient to perform nominal and emergency tasks? **[ISS 2, Lunar 1, Mars 1]**
26i	What characteristics of equipment, tool and computer displays; instructions, procedures, labels and warning; and human-computer interaction designs will maintain critical sensory and cognitive capabilities? **[ISS 2, Lunar 2, Mars 2]**
26j	What approaches to human computer interactions will maintain crew critical capabilities to assess, control and communicate? **[ISS 2, Lunar 2, Mars 2]**
26k	What decision-support systems are required to aid crew decision-making? **[ISS 2, Lunar 2, Mars 2]**
26l	What design considerations are needed to accommodate effects of changes in gravity on perception (Launch, lunar landing, lunar launch, Earth return)? **[ISS N/A, Lunar 1, Mars 1]**

Related Risks :

Sensory-Motor Adaptation
Impaired Sensory-Motor Capability to Perform Operational Tasks During Flight, Entry, and Landing
Impaired Sensory-Motor Capability to Perform Operational Tasks After Landing and Throughout Re-Adaptation
Clinical Capabilities
Medical Informatics, Technologies, and Support Systems
Medical Skill Training and Maintenance
Behavioral Health & Performance and Space Human Factors (Cognitive)
Human Performance Failure Due to Poor Psychosocial Adaptation
Human Performance Failure Due to Neurobehavioral Problems
Human Performance Failure Due to Sleep Loss and Circadian Rhythm Problems
Space Human Factors Engineering

	Mismatch Between Crew Physical Capabilities and Task Demands Poorly Integrated Ground, Crew, and Automation Functions
Important References :	Ellis SR. Collision in space. Ergonomics in Design. 8(1): 4-9, 2000. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=12162316 Human Space flight: Mission Analysis and Design, eds. W.J. Larson, L.K. Pranke. McGraw Hill Space Technology Series. 1999. Sleep, performance, circadian rhythms and light-dark cycles during two space Shuttle flights. Dijk DJ, Neri DF, Wyatt JK, Ronda JM, Riel E, Ritz-De Cecco A, Hughes RJ, Elliott AR, Prisk GK, West JB, Czeisler CA. Am J Physiol Regul Integr Comp Physiol. 2001 Nov; 281(5):R1647-64. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=11641138 Handbook of Human Factors and Ergonomics (2nd ed), G. Salvendy, ed. John Wiley and Sons, Inc. 1997. Handbook of Human Factors Testing and Evaluation, 2nd ed. S. G. Charlton, T.G. O?Brien, eds. 2002. Woolford B, Hudy CE, Whitmore M, Berman A, Maida J, and Pandya A. (2002) In Situ Training Project: LMLSTP Phase III Report. In Lane, H.W., Sauer, R.L. and Feeback, D.L. (Eds.), ISOLATION: NASA Experiments in Closed Environment Living. Advanced Human Life Support Enclosed System Final Report. San Diego, CA: American Astronautical Society.

Risk Title: Human Performance Failure Due to Sleep Loss and Circadian Rhythm Problems

Crosscutting Area :	Behavioral Health and Performance (BHP)
Discipline :	Behavioral Health & Performance and Space Human Factors (Cognitive)
Risk Number :	27
Risk Description :	Human performance failure may occur due to circadian disruption, and acute or chronic degradation of sleep quality and quantity.
Context / Risk Factors :	Circadian disruption, or acute or chronic degradation of sleep quality or quantity, is a known risk during space flight. This risk may be influenced by artificial and transmitted ambient light exposure, individual differences in vulnerability to sleep loss and circadian dynamics, or work shift and sleep schedules.
Justification / Rationale :	Loss of circadian entrainment to Earth-based light-dark cycles, and chronic reduction of sleep duration in space, result in fatigue and jeopardize astronaut performance. Fatigue is a common symptom in prolonged space flight. Every study of sleep in space, including those on US, Russian, and European astronauts, has found that daily sleep is reduced to an average of 6 hours. It is reduced even more when critical operations occur, such as nighttime Shuttle dockings on ISS, or during an emergency (e.g., equipment failure). Astronaut sleep in space is also physiologically altered. Additionally, the most frequent medications taken in-flight by astronauts are hypnotics for sleep disturbances. Extensive ground-based scientific evidence documents that circadian disruptions and restriction of sleep at levels commonly experienced by astronauts can severely diminish cognitive performance capability, posing risks to individual astronaut safety and mission success.
Risk Rating :	**ISS:** Priority 3 **Lunar:** Priority 3 **Mars:** Priority 2
Current Countermeasures :	• Bright light entrainment prior to launch • Individual active noise cancellation at sleep • Medications • Scheduling constraints, as documented in Ground Rules & Constraints document SSP 50261-2, to protect sleep schedule and duration, and reduce crew fatigue

<table>
<tr><td></td><td>

- Self report monitoring during mission with personal physician conference

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<tr><td>Projected Countermeasures or Mitigations & other Deliverables:</td><td>

- Ability to monitor sleep, circadian and lighting parameters unobtrusively in order to predict physiological and behavioral responses [CRL 7]
- Develop flight rule limits on critical operations during sleep period [CRL 4]
- Model of performance deficit based on sleep and circadian data [CRL 6]
- Personal lighting device (e.g., light visor) [CRL 6]
- Sleep/circadian rhythm non-photic adjustment tools pre- in- and post-flight [CRL 5]
- Sleep/circadian rhythm pharmacological interventions pre- in- and post-flight. [CRL 5]
- Sleep/circadian rhythm photic adjustment tools pre- in- and post-flight [CRL 7]

</td></tr>
<tr><td>Research & Technology Questions [With Mission Priority]:</td><td>
<table>
<tr><th>No.</th><th>Question</th></tr>
<tr><td>27a</td><td>What are the acute and long-term effects of exposure to the space environment on biological rhythmicity, sleep architecture (quantity and quality), and their relationship to performance capability? [ISS 1, Lunar 1, Mars 1]</td></tr>
<tr><td>27b</td><td>Which countermeasures or combination of behavioral and physiological countermeasures will optimally mitigate specific performance problems associated with sleep loss and circadian disturbances during the reference missions? [ISS 1, Lunar 1, Mars 1]</td></tr>
<tr><td>27c</td><td>What are the long-term effects of countermeasures employed to mitigate pre, - in- and post-flight performance problems with sleep loss and circadian disturbances? [ISS 3, Lunar 4, Mars 2]</td></tr>
<tr><td>27d</td><td>What are the best methods for in-flight monitoring of the status of sleep, circadian functioning and light exposures for assessing the effects of sleep loss and circadian dysrhythmia on performance capability that are also portable and non-intrusive in the space flight environment? (e.g., actigraphy) [ISS 2, Lunar 2, Mars 2]</td></tr>
<tr><td>27e</td><td>What work, workload, and sleep schedule(s) will best enhance crew performance and mitigate adverse effects of the space environment? [ISS 1, Lunar 1, Mars 1]</td></tr>
<tr><td>27f</td><td>What individual biological and behavioral characteristics will best predict successful adaptation to long-term space flight of sleep, circadian physiology and the neurobehavioral performance functions they regulate? [ISS 4, Lunar 5, Mars 1]</td></tr>
<tr><td>27g</td><td>What mathematical and computational models should be used to predict performance associated with sleep-wake, schedule, work history, light exposure and circadian rhythm status and also provide guidelines for successful countermeasure strategies? [ISS 1, Lunar 1, Mars 1]</td></tr>
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<tr><td>Related Risks :</td><td>
<table>
<tr><td>Clinical Capabilities</td></tr>
<tr><td>Pharmacology of Space Medicine Delivery</td></tr>
<tr><td>Ambulatory Care</td></tr>
<tr><td>Behavioral Health & Performance and Space Human Factors (Cognitive)</td></tr>
<tr><td>Human Performance Failure Due to Poor Psychosocial Adaptation</td></tr>
<tr><td>Human Performance Failure Due to Neurobehavioral Problems</td></tr>
<tr><td>Mismatch between Crew Cognitive Capabilities and Task Demands</td></tr>
<tr><td>Radiation</td></tr>
<tr><td>Acute and Late CNS Risks</td></tr>
<tr><td>Acute Radiation Risks</td></tr>
<tr><td>Space Human Factors Engineering</td></tr>
<tr><td>Mismatch Between Crew Physical Capabilities and Task Demands</td></tr>
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Risk Title: Carcinogenesis

Crosscutting Area :	Radiation Health (RH)
Discipline :	Radiation

<table>
<tr><td>Risk Number :</td><td>28</td></tr>
<tr><td>Risk Description :</td><td>Increased cancer morbidity or mortality risk in astronauts may be caused by occupational radiation exposure.</td></tr>
<tr><td>Context / Risk Factors :</td><td>This risk may be influenced by other space flight factors including microgravity and environmental contaminants. A Mars mission will not be feasible unless improved shielding is developed.</td></tr>
<tr><td>Justification / Rationale :</td><td>Exposure to space radiation increases the risk of developing cancer later in life.</td></tr>
<tr><td>Risk Rating :</td><td>ISS: Priority 2
Lunar: Priority 1
Mars: Priority 1</td></tr>
<tr><td>Current Countermeasures :</td><td>• Polyethylene shielding
• Mission design (altitude, vehicle attitude, timing of EVAÆs)
• Real-time monitoring
• Administrative radiation exposure limits (ALARA)</td></tr>
<tr><td>Projected Countermeasures or Mitigations & other Deliverables:</td><td>• Anti-oxidants [CRL 1]
• Gene therapy [CRL 1]
• Pharmaceuticals [CRL 1]
• Improved shielding and vehicle design to minimize radiation exposure [TRL 5]</td></tr>
<tr><td>Research & Technology Questions [With Mission Priority]:</td><td>
<table>
<tr><th>No.</th><th>Question</th></tr>
<tr><td>28a</td><td>What are the probabilities for increased carcinogenesis from space radiation as a function of NASA's operational parameters (age at exposure, age, latency, gender, tissue, mission, radiation quality, dose rate and exposure protraction)? [ISS 1, Lunar 1, Mars 1]</td></tr>
<tr><td>28b</td><td>How can tissue specific probabilities for increased carcinogenesis risk from space radiation be best evaluated? What molecular, genetic, epigenetic, abscopal (effect that irradiation of a tissue has on remote non-irradiated tissue), and other factors contribute to the tissue specificity of carcinogenic risk? [ISS 1, Lunar 1, Mars 1]</td></tr>
<tr><td>28c</td><td>How can the individual's sensitivity to radiation carcinogenesis be estimated? [ISS 2, Lunar 2, Mars 1]</td></tr>
<tr><td>28d</td><td>How can effective biomarkers of carcinogenic risk from space radiation be developed and validated? [ISS 3, Lunar 3, Mars 2]</td></tr>
<tr><td>28e</td><td>What are the most effective biomedical or dietary countermeasures to mitigate cancer risks? By what mechanisms are the countermeasures expected to work, and do they have the same efficiency for low- and high-LET radiation? [ISS 3, Lunar 3, Mars 1]</td></tr>
<tr><td>28f</td><td>How can animal models (including genetic models such as those developed by gene targeting or the use of other transgenic approaches) of carcinogenesis be developed to improve estimates of cancers from space radiation and what longitudinal studies are needed? [ISS 2, Lunar 2, Mars 1]</td></tr>
<tr><td>28g</td><td>What improvements can be made to quantitative procedures or theoretical models in order to extrapolate molecular, cellular, or animal results to determine the risks of specific cancers in astronauts? How can human epidemiology data best support these procedures or models? [ISS 3, Lunar 3, Mars 2]</td></tr>
<tr><td>28h</td><td>Are there significant combined effects from other space flight factors (microgravity, stress, altered circadian rhythms, changes in immune responses, viral reactivation etc.) that modify the carcinogenic risk from space radiation? [ISS 5, Lunar 5, Mars 3]</td></tr>
<tr><td>28i</td><td>What are the probabilities that space radiation will produce DNA damage at specific sites, including clustered DNA damage? What is the likelihood that DNA damage will increase the risk of carcinogenesis? [ISS 3, Lunar 3, Mars 2]</td></tr>
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	28j	What mechanisms modulate radiation damage at the molecular level (e.g., repair, errors in repair, signal transduction, gene amplification, bystander effects, tissue microenvironment, etc.) that significantly impact the risk of cancers, modulate the expression of radiation damage and decrease the radiation risk, and how can the understanding of mechanisms be used to predict carcinogenic risks from space radiation? **[ISS 2, Lunar 2, Mars 1]**
	28k	What space validation experiments could improve estimates of carcinogenic risks for long-term deep-space missions? **[ISS 5, Lunar 5, Mars 3]**
	28l	What are the most effective shielding approaches to mitigate cancer risks? **[ISS 1, Lunar 1, Mars 1]**
	28m	What new materials or active shielding methods can be used for reducing space radiation cancer risks? **[ISS 1, Lunar 1, Mars 1]**
	28n	What are the most effective approaches to integrate radiation shielding analysis codes with collaborative engineering design environments used by spacecraft and planetary habitat design efforts? **[ISS 4, Lunar 1, Mars 1]**
	28o	What is the most effective approach to use data from robotic Mars probes on the atmospheric, soil, and magnetic properties of the red planet for estimating carcinogenesis risk, and designing effective shielding or biological countermeasures? **[ISS 5, Lunar 5, Mars 2]**
	28p	What are the critical nuclear interaction experimental data and predictive theoretical models needed to complete radiation shielding analysis codes in support of exploration spacecraft and planetary habitat designs? **[ISS 5, Lunar 2, Mars 1]**

Related Risks :	**Immunology & Infection**
	Immune Dysfunction, Allergies and Autoimmunity
	Interaction of Space flight Factors, Infections and Malignancy
	Nutrition
	Inadequate Nutrition
	Clinical Capabilities
	Pharmacology of Space Medicine Delivery
	Behavioral Health & Performance and Space Human Factors (Cognitive)
	Human Performance Failure Due to Poor Psychosocial Adaptation
	Human Performance Failure Due to Neurobehavioral Problems
	Human Performance Failure Due to Sleep Loss and Circadian Rhythm Problems
	Radiation
	Acute and Late CNS Risks
	Chronic and Degenerative Tissue Risks
	Acute Radiation Risks
	Advanced Environmental Monitoring & Control
	Monitor External Environment

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Risk Title: Acute and Late CNS Risks

Crosscutting Area :	Radiation Health (RH)
Discipline :	Radiation
Risk Number :	29
Risk Description :	Acute and late radiation damage to the central nervous system (CNS) may lead to changes in motor function and behavior, or neurological disorders. This may be caused by occupational radiation exposure or the combined effects of radiation and other space flight factors.
Context / Risk Factors :	Radiation (space, medical diagnostic, atmospheric, experimental and nuclear sources including propulsion systems) and synergistic effects of radiation with other space flight factors may affect neural tissues, which in turn may lead to changes in function or behavior.
Justification / Rationale :	Crew health and performance in-flight may be affected.This risk will be most significant during a Mars mission, with a long travel time and no return capability.
Risk Rating :	**ISS:** Priority 2 **Lunar:** Priority 2

	Mars: Priority 1
Current Countermeasures :	• Polyethylene shielding • Avoidance of the South Atlantic Anomaly (SAA) • ALARA, and monitoring of exposure limits • Vehicle altitude and attitude changes
Projected Countermeasures or Mitigations & other Deliverables:	• Anti-oxidants [CRL 1] • Hydrogenous shielding [TRL 5] • Pharmaceuticals [CRL 1] • Autonomous monitoring [Lunar] [Mars] • Improved shielding materials [Lunar] [Mars] • Pharmacological cellular protectants will be required [Lunar] [Mars]
Research & Technology Questions [With Mission Priority]:	(see table below)
Related Risks :	**Bone Loss**

Research & Technology Questions [With Mission Priority]:

No.	Question
29a	Is there a significant probability that space radiation would lead to immediate or acute functional changes in the CNS due to a long-term space mission and if so what are the mechanisms of change? **[ISS 3, Lunar 3, Mars 1]**
29b	Is there a significant probability that space radiation exposures would lead to long-term or late degenerative CNS risks? If so what are the mechanisms of change? **[ISS 3, Lunar 3, Mars 1]**
29c	How does individual susceptibility including hereditary pre-disposition (Alzheimer's, Parkinson's, apoE) and prior CNS injury (concussion or other) alter significant CNS risks? **[ISS 3, Lunar 3, Mars 1]**
29d	What are the most effective biomedical or dietary countermeasures to mitigate CNS risks? By what mechanisms do the countermeasures work? **[ISS 4, Lunar 4, Mars 1]**
29e	How can animal models of CNS risks, including altered motor and cognitive function, behavioral changes and late degenerative risks be best used for estimating space radiation risks to astronauts? **[ISS 4, Lunar 3, Mars 1]**
29f	Are there significant CNS risks from combined space radiation and other physiological or space flight factors (e.g., bone loss, microgravity, immune-endocrine systems or other)? **[ISS 5, Lunar 5, Mars 3]**
29g	What are the molecular, cellular and tissue mechanisms of damage [DNA damage processing, oxidative damage, cell loss through apoptosis or necrosis, changes in the extra-cellular matrix, cytokine activation, inflammation, changes in plasticity, micro-lesion (clusters of damaged cells along heavy ion track) etc.] in the CNS? **[ISS 4, Lunar 3, Mars 1]**
29h	What are the different roles of neural cell populations, including neuronal stem cells and their integrative mechanisms in the morphological and functional consequences of space radiation exposure? **[ISS 2, Lunar 2, Mars 1]**
29i	Are there biomarkers for detecting damage or susceptibility to/for radiation-induced CNS damage? **[ISS 4, Lunar 3, Mars 2]**
29j	What quantitative procedures or theoretical models are needed to extrapolate molecular, cellular, or animal results to predict CNS risks in astronauts? How can human epidemiology data best support these procedures or models? **[ISS 4, Lunar 3, Mars 2]**
29k	What are the most effective shielding approaches to mitigate CNS risks? **[ISS 1, Lunar 1, Mars 1]**
29l	What space validation experiments could improve estimates of CNS risks for long-term deep-space missions? **[ISS 5, Lunar 5, Mars 3]**

	Accelerated Bone Loss and Fracture Risk
	Cardiovascular Alterations
	Occurrence of Serious Cardiac Dysrhythmias
	Immunology & Infection
	Immune Dysfunction, Allergies and Autoimmunity
	Interaction of Space flight Factors, Infections and Malignancy
	Sensory-Motor Adaptation
	Impaired Sensory-Motor Capability to Perform Operational Tasks During Flight, Entry, and Landing
	Impaired Sensory-Motor Capability to Perform Operational Tasks After Landing and Throughout Re-Adaptation
	Nutrition
	Inadequate Nutrition
	Clinical Capabilities
	Monitoring and Prevention
	Major Illness and Trauma
	Pharmacology of Space Medicine Delivery
	Ambulatory Care
	Behavioral Health & Performance and Space Human Factors (Cognitive)
	Human Performance Failure Due to Neurobehavioral Problems
	Radiation
	Carcinogenesis
	Chronic and Degenerative Tissue Risks
	Acute Radiation Risks
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	Surma-aho O, et al. Adverse Long-Term Effects of Brain Radiotherapy in Adult Low-Grade Glioma Patients. Neurology. 56: 1285-1290, 2001. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=11376174

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Risk Title: Chronic and Degenerative Tissue Risks

Crosscutting Area :	Radiation Health (RH)
Discipline :	Radiation
Risk Number :	30
Risk Description :	Radiation exposure may result in degenerative tissue diseases (non-cancer or non-CNS) such as cardiac, circulatory, or digestive diseases, as well as cataracts. This may be caused by occupational radiation exposure or the combined effects of radiation and other space flight factors.
Context / Risk Factors :	Radiation (space, medical diagnostic, atmospheric, experimental and nuclear sources including propulsion systems) and synergistic effects of radiation cause increased DNS strand and tissue degeneration, which may lead to acute or chronic disease of susceptible organ tissues. The risk may also be influenced by microgravity or physiological changes.
Justification / Rationale :	Acute or chronic illness due to tissue degeneration may lead to mission impacts, or adverse health consequences after return.
Risk Rating :	**ISS:** Priority 2 **Lunar:** Priority 2 **Mars:** Priority 1
Current Countermeasures :	• Polyethylene shielding • Avoidance of the South Atlantic Anomaly (SAA) • ALARA, and monitoring of exposure limits • Vehicle altitude and attitude changes
Projected Countermeasures or Mitigations & other Deliverables:	• Anti-oxidants [CRL 1] • Hydrogenous shielding [TRL 5] • Pharmaceuticals [CRL 1] • Autonomous monitoring [Lunar] [Mars] • Improved shielding materials [Lunar] [Mars] • Pharmacological cellular protectants [Lunar] [Mars]
Research & Technology Questions [With Mission Priority]:	(see table below)

No.	Question
30a	What are the probabilities for degenerative tissue risks from protons and HZE ions as a function of NASA's operational parameters (age at exposure, age and time after exposure, gender, tissue, mission, radiation quality, dose rate)? **[ISS 2, Lunar 2, Mars 1]**
30b	What are the mechanisms of degenerative tissues risks in the heart, circulatory, endocrine, digestive, lens and other tissue systems? **[ISS 2, Lunar 2, Mars 1]**
30c	How can the latency period for degenerative tissue risks, including sub-clinical diseases, following space radiation exposures be estimated? **[ISS 3, Lunar 3, Mars 1]**

	30d	What are the most effective biomedical or dietary countermeasures to degenerative tissue risks? By what mechanisms do the countermeasures work? **[ISS 3, Lunar 3, Mars 1]**
	30e	What quantitative procedures or theoretical models are needed to extrapolate molecular, cellular, or animal results to predict degenerative tissue risks in astronauts? How can human epidemiology data best support these procedures or models? **[ISS 4, Lunar 4, Mars 2]**
Related Risks :	**Cardiovascular Alterations**	
	Occurrence of Serious Cardiac Dysrhythmias	
	Immunology & Infection	
	Immune Dysfunction, Allergies and Autoimmunity	
	Interaction of Space flight Factors, Infections and Malignancy	
	Skeletal Muscle Alterations	
	Increased Susceptibility to Muscle Damage	
	Nutrition	
	Inadequate Nutrition	
	Clinical Capabilities	
	Monitoring and Prevention	
	Pharmacology of Space Medicine Delivery	
	Radiation	
	Carcinogenesis	
	Acute and Late CNS Risks	
	Acute Radiation Risks	
Important References :	Berrington A., et al. 100 Years of observation of British radiologists: mortality from cancer and other causes 1897-1997. Br J Radio. 74:507-519, 2001. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=12595318	
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Risk Title: Acute Radiation Risks

Crosscutting Area :	Radiation Health (RH)
Discipline :	Radiation
Risk Number :	31
Risk Description :	Acute radiation syndromes may occur due to occupational radiation exposure.
Context / Risk Factors :	Radiation (space, medical diagnostic, atmospheric, experimental and nuclear sources including propulsion systems) and synergistic effects of radiation may place the crew at significant risk for acute radiation sickness, such that the mission or crew survival may be placed in jeopardy.
Justification / Rationale :	Crew health and performance may be impacted by acute solar events. Beyond Low Earth Orbit, the protection of the Earth's atmosphere is no longer available, such that increased shielding and protective mechanisms are necessary in order to prevent acute radiation sickness and impacts to mission success or crew survival.
Risk Rating :	**ISS:** Priority 3 **Lunar:** Priority 2 **Mars:** Priority 1
Current Countermeasures :	• Polyethylene shielding • Avoidance of the South Atlantic Anomaly (SAA) • Vehicle altitude and attitude changes • ALARA, and monitoring of radiation exposure limits
Projected Countermeasures or Mitigations & other Deliverables:	• Anti-oxidants [CRL 1] • Hydrogenous shielding [TRL 5] • Pharmaceuticals [CRL 1] • Autonomous monitoring [Lunar] [Mars] • Improved shielding materials [Lunar] [Mars] • Pharmacological cellular protectants [Lunar] [Mars]
Research & Technology Questions [With Mission Priority]:	**No.** | **Question**

	31a	How can predictions of acute space radiation events be improved? **[ISS 5, Lunar 3, Mars 3]**
	31b	Are there synergistic effects arising from other space flight factors (microgravity, stress, immune status, bone loss, damage to intestinal cells reducing their ability to absorb medication etc.) that modify acute risks from space radiation including modifying thresholds for such effects? **[ISS 4, Lunar 3, Mars 3]**
	31c	What are the molecular, cellular and tissue mechanisms of acute radiation damage (DNA damage processing, oxidative damage, cell loss through apoptosis or necrosis, cytokine activation, etc.)? **[ISS 4, Lunar 3, Mars 3]**
	31d	Does protracted exposure to space radiation modify acute doses from SPEs in relationship to acute radiation syndromes? **[ISS 4, Lunar 3, Mars 3]**
	31e	What are the most effective biomedical or dietary countermeasures to mitigate acute radiation risks? By what mechanisms do the countermeasures work? **[ISS 4, Lunar 3, Mars 3]**
	31f	What quantitative procedures or theoretical models are needed to extrapolate molecular, cellular, or animal results to predict acute radiation risks in astronauts? How can human epidemiology data best support these procedures or models? **[ISS 4, Lunar 3, Mars 3]**
	31g	What are the most effective shielding approaches to mitigate acute radiation risks? **[ISS 1, Lunar 1, Mars 1]**
	31h	What are the most effective "storm shelter" shielding approaches to protect against large solar particle events in deep space or on planetary surfaces? **[ISS 3, Lunar 1, Mars 1]**

Related Risks :	**Bone Loss**
	Accelerated Bone Loss and Fracture Risk
	Cardiovascular Alterations
	Occurrence of Serious Cardiac Dysrhythmias
	Immunology & Infection
	Immune Dysfunction, Allergies and Autoimmunity
	Interaction of Space flight Factors, Infections and Malignancy
	Nutrition
	Inadequate Nutrition
	Clinical Capabilities
	Monitoring and Prevention
	Major Illness and Trauma
	Pharmacology of Space Medicine Delivery
	Behavioral Health & Performance and Space Human Factors (Cognitive)
	Human Performance Failure Due to Neurobehavioral Problems
	Radiation
	Carcinogenesis
	Acute and Late CNS Risks
	Chronic and Degenerative Tissue Risks
	Advanced Environmental Monitoring & Control
	Monitor External Environment

Important References :	Ainsworth EJ. Early and late mammalian responses to heavy charged particles. Advances in Space Research. 6: 153-165, 1986. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=11537215 National Council on Radiation Protection and Measurements, NCRP. Guidance on Radiation Received in Space Activities, NCRP Report 98, NCRP, Bethesda (MD), 1989. National Council on Radiation Protection and Measurements, Recommendations of Dose Limits for Low Earth Orbit. NCRP Report 132, Bethesda MD, 2000. Todd P, Pecautt MJ, Fleshner M. Combined effects of space flight factors and radiation on humans. Mutation Res. 430: 211-219, 1999. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=10631335

Risk Title: Monitor Air Quality

Crosscutting Area :	Advanced Human Support Technologies (AHST)
Discipline :	Advanced Environmental Monitoring & Control
Risk Number :	32
Risk Description :	Lack of timely chemical and microbial detection in the crew atmosphere, or elsewhere in the air processing system, can lead to delayed response by the crew or by automated response equipment, leading to increased hazards to the crew.
Context / Risk Factors :	Chemical and microbial detection in the crew atmosphere, or elsewhere in the air processing system, can indicate the buildup of microbial contaminants, hazardous chemicals, pre-combustion reaction products, malfunction of life support equipment, or other hazardous events such as accidental release from an experiment. This risk may be influenced by accidental events such as fire or leak, or a malfunction in the life support system, which may be gradual or sudden.
Justification / Rationale :	Technologies must be able to detect both anticipated and unanticipated events and identify the problem source. Gradual buildup of toxic chemicals may take months, calling for highly sensitive detection at slow intervals, perhaps daily. Leakage or pre-combustion events are expected to occur more rapidly, requiring more rapid detection (minutes), though less sensitive detection may be necessary. Existing technology is critical resource intensive and requires substantial improvement in efficiency, reliability, and functionality. For example, no single technology currently can address all Spacecraft Maximum Allowable Concentration (SMAC) chemicals, combustion in micro, lunar and Martian gravity is very different from combustion on Earth and has different pre-combustion indicators, and harmful foreign matter may be inadvertently brought in following extravehicular activity (EVA). The same monitoring technology may be useful for helping diagnose crew health by providing breath-monitoring data.
Risk Rating :	**ISS:** Priority 2 **Lunar:** Priority 1 **Mars:** Priority 1
Current Countermeasures :	• ISS Compound Specific Combustion Product Analyzer • Crew indicators such as reports of odor, nausea • Ground analysis of returned samples • ISS Major Constituent Analyzer • ISS Volatile Organic Analyzer • Materials selection • Scheduled maintenance and housekeeping
Projected Countermeasures or Mitigations & other Deliverables:	• Distributed network of rapid, smaller detectors [TRL 4] • Highly sensitive somewhat slower analyzer suite [TRL 4]

Research & Technology Questions [With Mission Priority]:	<table><tr><th>No.</th><th>Question</th></tr><tr><td>32a</td><td>What technologies can be used to detect slow, gradual changes in the chemical and microbial environment ?(work with Environmental Health) [ISS 1, Lunar 1, Mars 1]</td></tr><tr><td>32b</td><td>What set of technologies and data can be used to quickly diagnose potentially hazardous events from chemical data? [ISS 1, Lunar 1, Mars 1]</td></tr><tr><td>32c</td><td>How can environmental information be used to assist in-flight biomonitoring for health and performance of the astronauts (supporting Biomedical monitoring)? [ISS 3, Lunar 3, Mars 3]</td></tr><tr><td>32d</td><td>What technologies must be developed to rapidly detect and address fire in space? [ISS 1, Lunar 1, Mars 1]</td></tr><tr><td>32e</td><td>How can technology help ensure that appropriate responses to hazardous events are achieved in a timely manner? [ISS 2, Lunar 2, Mars 2]</td></tr><tr><td>32f</td><td>What set of technologies and data can be used to detect and diagnose hardware malfunction, in such systems as life support or in situ resource utilization by assessment of environmental (air, water, or surfaces) changes? (work with ALS) [ISS 2, Lunar 2, Mars 2]</td></tr><tr><td>32g</td><td>What technologies can detect both anticipated and unanticipated species and events? [ISS 1, Lunar 1, Mars 1]</td></tr></table>
Related Risks :	<table><tr><td>Environmental Health</td></tr><tr><td>Define Acceptable Limits for Contaminants in Air and Water</td></tr><tr><td>Clinical Capabilities</td></tr><tr><td>Monitoring and Prevention</td></tr><tr><td>Advanced Environmental Monitoring & Control</td></tr><tr><td>Monitor External Environment</td></tr><tr><td>Provide Integrated Autonomous Control of Life Support Systems</td></tr><tr><td>Advanced Life Support</td></tr><tr><td>Maintain Acceptable Atmosphere</td></tr><tr><td>Maintain Thermal Balance in Habitable Areas</td></tr><tr><td>Provide and Maintain Bioregenerative Life Support Systems</td></tr><tr><td>Space Human Factors Engineering</td></tr><tr><td>Mismatch Between Crew Physical Capabilities and Task Demands</td></tr></table>
Important References :	<table><tr><td>"Cabin Air Quality Dynamics on Board the International Space Station" J Perry, B Peterson, 33rd International Conference on Environmental Systems, SAE#2003-01-2650, July 2003.</td></tr><tr><td>"Toxicological Assessment of the International Space Station Atmosphere with Emphasis on Metox Canister Regeneration" J James, 33rd International Conference on Environmental Systems, SAE#2003-01-2647, July 2003.</td></tr><tr><td>Advanced Technology for Human Support in Space, National Research Council Report, 1997. Downloadable from http://peer1.nasaprs.com/peer_review/prog/nap.pdf http://peer1.nasaprs.com/peer_review/prog/nap.pdf</td></tr><tr><td>NASA/JSC Toxicology Group Home Page http://www.jsc.nasa.gov/toxicology/ http://www.jsc.nasa.gov/toxicology/</td></tr></table>

Risk Title: Monitor External Environment

Crosscutting Area :	Advanced Human Support Technologies (AHST)
Discipline :	Advanced Environmental Monitoring & Control

Risk Number :	33
Risk Description :	Failure to detect hazards external to the habitat (e.g., dust, fuel contaminants) can lead to lack of remedial action, and poses an increased risk to the crew.
Context / Risk Factors :	Potentially harmful substances may exist external to the habitat. They may be generated by the spacecraft, such as fuel or hydraulic residue, or they may be native to the environment, such as erosive or chemically reactive dust.
Justification / Rationale :	Possible events include leakage of ammonia coolant, of cabin atmosphere, or of rocket propellant. The lunar or Martian environment itself may have some hazard such as the chemical composition or physical nature of the dust. It is expected that in some cases these can be readily detected during extravehicular activity (EVA).
Risk Rating :	**ISS:** Priority 2 **Lunar:** Priority 1 **Mars:** Priority 1
Current Countermeasures :	• ISS Trace Gas Analyzer (TGA) using miniature quadrupole mass spectrometry technology • Procedures for decontamination and monitoring and cleanup following chemical exposure while EVA
Projected Countermeasures or Mitigations & other Deliverables:	• Real-time radiation monitor [TRL 4] • Second generation TGA [TRL 6]
Research & Technology Questions [With Mission Priority]:	**No.** / **Question** 33a: What sensors are required to monitor hazardous conditions in the extra-vehicular environment? (work with AEVA) **[ISS 1, Lunar 1, Mars 1]**
Related Risks :	**Environmental Health** Define Acceptable Limits for Contaminants in Air and Water **Clinical Capabilities** Monitoring and Prevention **Radiation** Carcinogenesis Acute Radiation Risks **Advanced Environmental Monitoring & Control** Monitor Air Quality **Advanced Extravehicular Activity** Provide Space Suits and Portable Life Support Systems
Important References :	"Trace Gas Analyzer for Extra-Vehicular Activity" T Abbasi, M Christensen, M Villemarette, M Darrach, A Chutjian, 31st International Conference on Environmental Systems, SAE#2001-01-2405, July 2001.

Risk Title: Monitor Water Quality

Crosscutting Area :	Advanced Human Support Technologies (AHST)
Discipline :	Advanced Environmental Monitoring & Control
Risk Number :	34
Risk Description :	Lack of timely information about the build-up of chemicals or microbial growth in the crew water supply, or elsewhere in the water reclamation system, can lead to a delayed response by the crew, or the automated response equipment, and pose a hazard to the crew.
Context / Risk	This risk may be influenced by an accidental event such as a leak of ammonia from the cooling

Factors :	system into the water supply through the heat exchanger, or a malfunction in the life support system, which may be gradual or sudden.
Justification / Rationale :	Gradual buildup of toxic chemicals may take months, calling for highly sensitive detection at slow intervals, perhaps daily. Leakage events are expected to occur more rapidly, requiring more rapid detection (minutes), though less sensitive detection may be necessary. Technologies must be able to detect both anticipated and unanticipated events and phenomena. Localized information is needed to identify the problem source. Existing technology for ground-based measurement is massive, power hungry, needs hazardous reagents, requires significant crew skill and time and is sensitive to micro, lunar, or Martian gravity multiphase issues.
Risk Rating :	**ISS:** Priority 2 **Lunar:** Priority 1 **Mars:** Priority 1
Current Countermeasures :	• Crew report of odor or taste • Ground analysis of returned samples • Manual plate culturing at ambient temperature with visual estimate • Water conductivity measurement • ISS Total Organic Carbon Analyzer
Projected Countermeasures or Mitigations & other Deliverables:	• Compact online chemical water analyzer suite [TRL 3] • Microbial analysis instrument [TRL 3]
Research & Technology Questions [With Mission Priority]:	

No.	Question
34a	What technologies can be used to detect slow, gradual changes in the chemical and microbial environment? (work with ALS and Environmental Health) **[ISS 1, Lunar 1, Mars 1]**
34b	What set of technologies and data can be used to quickly diagnose potentially hazardous events from chemical data? **[ISS 1, Lunar 1, Mars 1]**
34c	How can technology help ensure that appropriate responses to hazardous events are achieved in a timely manner? (Needed for developing automated systems.) **[ISS 2, Lunar 2, Mars 2]**
34d	What set of technologies and data can be used to detect and diagnose hardware malfunction by assessment of environmental (air, water, or surfaces) changes? (work with ALS) **[ISS 1, Lunar 1, Mars 1]**
34e	What technologies can detect both anticipated and unanticipated species and events? **[ISS 1, Lunar 1, Mars 1]**

Related Risks :

Environmental Health
Define Acceptable Limits for Contaminants in Air and Water
Clinical Capabilities
Monitoring and Prevention
Advanced Life Support
Maintain Acceptable Atmosphere
Provide and Maintain Bioregenerative Life Support Systems
Provide and Recover Potable Water

Important References :

"ISS Potable Water Sampling and Chemical Analysis: Expeditions 4-6" D Plumlee, P Mudgett, J Schultz, J James, 33rd International Conference on Environmental Systems, SAE#2003-01-2401, July 2003.

	Advanced Technology for Human Support in Space, National Research Council Report, 1997. Downloadable from http://peer1.nasaprs.com/peer_review/prog/nap.pdf http://peer1.nasaprs.com/peer_review/prog/nap.pdf AEMC Technology Development Requirements (1998) downloadable from http://peer1.nasaprs.com/peer_review/prog/prog.html http://peer1.nasaprs.com/peer_review/prog/prog.html Characterization and Monitoring of Microbial Species in the International Space Station Drinking Water. M LaDuc, 33rd International Conference on Environmental Systems, SAE#2003-01-2404, July 2003. NASA/JSC Toxicology Group Home Page http://www.jsc.nasa.gov/toxicology/ http://www.jsc.nasa.gov/toxicology/

Risk Title: Monitor Surfaces, Food, and Soil

Crosscutting Area :	Advanced Human Support Technologies (AHST)
Discipline :	Advanced Environmental Monitoring & Control
Risk Number :	35
Risk Description :	Lack of timely information, or failure to detect the presence of harmful chemicals or microbial growth on surfaces, food supplies, or soil (required for plant growth) can pose a crew health hazard.
Context / Risk Factors :	Low gravity environments allow for greater accumulation of liquids on surfaces by surface tension and longer persistence of matter suspended in air, increasing the likelihood of surface impact.
Justification / Rationale :	The area of contamination of surfaces in the space environment has received relatively little attention to date. The risk is essentially unknown.
Risk Rating :	**ISS:** Priority 2 **Lunar:** Priority 1 **Mars:** Priority 1
Current Countermeasures :	• Occasional manual plate culturing of samples from swabbed surfaces • Regular and as needed housecleaning
Projected Countermeasures or Mitigations & other Deliverables:	• Detection and identification of surface contamination by optical interrogation [TRL 3] • Reliable, repeatable sampling methods taking minimal crew time [TRL 2]
Research & Technology Questions [With Mission Priority]:	see below
Related Risks :	**Environmental Health** Define Acceptable Limits for Contaminants in Air and Water **Clinical Capabilities**

Research & Technology Questions [With Mission Priority]:

No.	Question
35a	What technologies can be used to detect slow, gradual changes in the chemical and microbial surface environment? (work with Environmental Health and ALS) **[ISS 1, Lunar 1, Mars 1]**
35b	What set of technologies and data can be used to quickly diagnose potentially hazardous events from chemical data? **[ISS 1, Lunar 1, Mars 1]**
35c	What technologies are required to meet the radiation monitoring requirements of a mission? **[ISS 2, Lunar 1, Mars 1]**
35d	What sample acquisition and preparation technologies can meet the requirements of the gaseous, aqueous and solid-phase matrices monitoring? **[ISS 1, Lunar 1, Mars 1]**
35e	What research is required to validate design approaches for multiphase flow for monitoring systems in varying gravity environments? **[ISS 1, Lunar 2, Mars 2]**

	Monitoring and Prevention **Advanced Food Technology** Maintain Food Quantity and Quality **Advanced Life Support** Maintain Acceptable Atmosphere
Important References :	Advanced Technology for Human Support in Space, National Research Council Report, 1997. Downloadable from http://peer1.nasaprs.com/peer_review/prog/nap.pdf http://peer1.nasaprs.com/peer_review/prog/nap.pdf AEMC Technology Development Requirements (1998) downloadable from http://peer1.nasaprs.com/peer_review/prog/prog.html http://peer1.nasaprs.com/peer_review/prog/prog.html

Risk Title: Provide Integrated Autonomous Control of Life Support Systems

Crosscutting Area :	Advanced Human Support Technologies (AHST)
Discipline :	Advanced Environmental Monitoring & Control
Risk Number :	36
Risk Description :	Lack of stable, reliable, efficient process control for the life support system can pose a hazard to crew health or create an excessive crew workload.
Context / Risk Factors :	Decreasing life support system mass by decreasing air or water buffer sizes (an economically desirable objective) increases the potential for the system to become unstable. Additionally, longer mission durations, such as with the Mars scenario, mean greater potential for the life support system to become unstable.
Justification / Rationale :	Automated control of life support is needed to minimize the crew workload. Industrial process control technology is manufacturing-oriented (input/output) with a narrow range of time constants. Space life support is an endless loop-recycling environment, with time constants ranging from fast accidental incidents to life cycles of plant crops (months). Advances in process control technology are needed for safe, efficient control of the life support system.
Risk Rating :	**ISS:** Priority 3 **Lunar:** Priority 2 **Mars:** Priority 1
Current Countermeasures :	• Manual and low level process control
Projected Countermeasures or Mitigations & other Deliverables:	• Automated control of life support, integrated with monitoring system [TRL 2]
Research & Technology Questions [With Mission Priority]:	

No.	Question
36a	How do we design an effective control system with flexibility, modularity, growth potential, anti-obsolescence and accommodate varied, new, & unknown test articles, taking advantage of standards? (work with Integrated Testing) **[ISS 1, Lunar 1, Mars 1]**
36b	How does a control system manage and plan for the long time constants of certain biological processes that lead to changes days, months later; and reconciles between discrete events, continuous processing and varying time constants? (work with Integrated Testing) **[ISS 1, Lunar 1, Mars 1]**
36c	How do we assure that human situation awareness is at a high level when needed, while offloading the crew workload for most of the time? (work with SHFE and Integrated Testing) **[ISS 2, Lunar 2, Mars 2]**

	36d	How can a control system support strategic decisions; launch readiness/abort/return home decisions and procedures? (work with SHFE and Integrated Testing) **[ISS 1, Lunar 1, Mars 1]**
	36e	How can we develop real time prognostic capabilities to predict failures before they occur and degradations before they have impact? (work with ALS and Integrated Testing) **[ISS 1, Lunar 1, Mars 1]**
	36f	How do we allocate efficiently and safely between space-based control and ground-based control? (work with SHFE and Integrated Testing) **[ISS 1, Lunar 1, Mars 1]**
	36g	In very large and complex systems, how can we synchronize system states across subsystems? (work with Integrated Testing) **[ISS 1, Lunar 1, Mars 1]**
	36h	How do we trade between buffers and controls to ensure safe and reliable system? (work with ALS and Integrated Testing) **[ISS 1, Lunar 1, Mars 1]**
	36i	How can understanding process control help determine which sensors may be missing and where sensors should be placed? (work with Integrated Testing) **[ISS 1, Lunar 1, Mars 1]**

Related Risks :	**Environmental Health**
	Define Acceptable Limits for Contaminants in Air and Water
	Advanced Environmental Monitoring & Control
	Monitor Air Quality
	Advanced Extravehicular Activity
	Provide Space Suits and Portable Life Support Systems
	Advanced Life Support
	Maintain Acceptable Atmosphere
	Provide and Maintain Bioregenerative Life Support Systems
	Provide and Recover Potable Water
	Space Human Factors Engineering
	Mismatch Between Crew Physical Capabilities and Task Demands
	Poorly Integrated Ground, Crew, and Automation Functions
Important References :	Advanced Technology for Human Support in Space, National Research Council Report, 1997. Downloadable from http://peer1.nasaprs.com/peer_review/prog/nap.pdf http://peer1.nasaprs.com/peer_review/prog/nap.pdf
	AEMC Technology Development Requirements (1998) downloadable from http://peer1.nasaprs.com/peer_review/prog/prog.html http://peer1.nasaprs.com/peer_review/prog/prog.html
	Final Report, Workshop on Advanced System Integration and Control for Life Support (ASICLS) Monterey Plaza Hotel , 26-28 August 2003, Monterey, CA
	NASA Advanced Environmental Monitoring and Control (AEMC) Program Review, Final Report, USRA, August 1999. Also, AEMC review response sent to HQ Sept 1999.

Risk Title: Provide Space Suits and Portable Life Support Systems

Crosscutting Area :	Advanced Human Support Technologies (AHST)
Discipline :	Advanced Extravehicular Activity
Risk Number :	37
Risk Description :	EVA performance and crew health may be compromised by inadequate EVA systems.
Context / Risk	This risk may be influenced by flight duration, lack of return and re-supply capability, limited on-

Factors :	board servicing capability, or dust contamination of suit bearings and joints.
Justification / Rationale :	Long-duration crew stays on moon and Mars lead to increased EVA hardware use. Lunar and Mars gravity levels cause suit weight to become a significant load on crewmembers. Hardware failures could occur without the capability for equipment servicing and overhaul. Lunar and Mars dust contamination leads to equipment failures and decreased suit mobility from contaminated bearings and joints
Risk Rating :	**ISS:** Priority 3 **Lunar:** Priority 2 **Mars:** Priority 1
Current Countermeasures :	• Dedicated water • Limited maintenance • Longer life rechargeable batteries • Regenerable CO_2 removal systems
Projected Countermeasures or Mitigations & other Deliverables:	• Cleaning and maintenance of soft goods (e.g., washing of LCVG) • Dust removal and dust prevention [Lunar] [Mars] • Increased on-orbit space suit service life • Longer shelf and service life batteries • Non-venting heat rejection system • Reduced mass of suit and PLSS [Lunar] [Mars] • Regenerable closed loop CO_2 removal systems
Research & Technology Questions [With Mission Priority]:	

No.	Question
37a	What EVA system design and minimum prebreathe protocol can be developed to reduce the risk of decompression sickness? **[ISS N/A, Lunar 1, Mars 1]**
37b	What suit and PLSS technology must be developed to meet mission requirements for EVA mobility? **[ISS N/A, Lunar 1, Mars 1]**
37c	How do we protect against planetary surface dust through suit and airlock system design? **[ISS N/A, Lunar 1, Mars 1]**
37d	How do we protect against toxic fluids and contaminants? **[ISS 2, Lunar 2, Mars 2]**
37e	How do we design space suits to fit multiple crewmembers of various sizes and shapes? **[ISS 1, Lunar 1, Mars 1]**
37f	How do we improve glove dexterity? **[ISS 1, Lunar 1, Mars 1]**
37g	What technologies can be developed to provide passive or active thermal insulation in various environments, including deep-space and lunar vacuum? **[ISS N/A, Lunar 1, Mars 1]**
37h	What technologies must be developed to meet mission non-venting and non-contaminating requirements? **[ISS N/A, Lunar 2, Mars 2]**
37i	How do we provide and manage increased information to EVA crewmembers, including suit parameters, systems status, caution and warning, video, sensor data, procedures, text, and graphics? **[ISS N/A, Lunar 2, Mars 2]**
37j	How do we achieve EVA and robotic interaction and cooperation? **[ISS N/A, Lunar 1, Mars 1]**
37k	What biomedical sensors are needed to enhance safety and performance during EVAs? **[ISS 4, Lunar 2, Mars 2]**
37l	How can space suit design accommodate a crewmember's physical changes from long-duration exposure to microgravity? **[ISS 4, Lunar 1, Mars 1]**

	<table><tr><td>37m</td><td>What technology can be developed to monitor EVA crewmember thermal status and provide auto-thermal control under both nominal operating and emergency conditions? [ISS N/A, Lunar 1, Mars 1]</td></tr><tr><td>37n</td><td>Can a practical EMU containment receptacle for emesis be developed? If a vomiting episode occurs, is there a way of refurbishing the suit during the mission? How can suit life support systems be designed to be more resistant to vomiting episode? [ISS 1, Lunar 1, Mars 1]</td></tr></table>
Related Risks :	<table><tr><td>Environmental Health</td></tr><tr><td>Define Acceptable Limits for Contaminants in Air and Water</td></tr><tr><td>Sensory-Motor Adaptation</td></tr><tr><td>Motion Sickness</td></tr><tr><td>Clinical Capabilities</td></tr><tr><td>Monitoring and Prevention</td></tr><tr><td>Major Illness and Trauma</td></tr><tr><td>Ambulatory Care</td></tr><tr><td>Medical Informatics, Technologies, and Support Systems</td></tr><tr><td>Advanced Environmental Monitoring & Control</td></tr><tr><td>Monitor External Environment</td></tr><tr><td>Provide Integrated Autonomous Control of Life Support Systems</td></tr><tr><td>Advanced Life Support</td></tr><tr><td>Maintain Thermal Balance in Habitable Areas</td></tr><tr><td>Provide and Maintain Bioregenerative Life Support Systems</td></tr></table>
Important References :	Advanced Technology for Human Support in Space, Committee on Advanced Technology for Human Support in Space, Aeronautics and Space Engineering Board, National Research Council, National Academy Press, Washington DC, 1997.

Risk Title: Maintain Food Quantity and Quality

Crosscutting Area :	Advanced Human Support Technologies (AHST)
Discipline :	Advanced Food Technology
Risk Number :	38
Risk Description :	Crew nutritional requirements may not be met and crew health and performance compromised due to inadequate food acceptability, preparation, processing, and storage systems.
Context / Risk Factors :	This risk may be influenced by sub-standard food intakes, chemical or microbial contamination of food, crew psychological and physiological changes, elevated stress and boredom, inadequate food packaging, inadequate food processing/preservation, inadequate quantity of food, inadequate shelf life, inadequate storage conditions and environmental control, inadequate variety, product formulation, or undefined nutritional requirements.
Justification / Rationale :	There must be means to provide the crew a sufficient, balanced, nutritious diet.
Risk Rating :	**ISS:** Priority 2 **Lunar:** Priority 3 **Mars:** Priority 1
Current Countermeasures :	• Hazard analysis critical control point processing • Increased menu cycle and menu variety • Menu developed based on daily nutritional requirements

<table>
<tr><td></td><td>

- Preflight food tasting and selection
- Vitamin and nutrient supplementation

</td></tr>
<tr><td>Projected Countermeasures or Mitigations & other Deliverables:</td><td>

- Assessment of food psychosocial importance [TRL 2]
- Determine effects of space radiation on food [TRL 1]
- Development of extended shelf life food through improved food preservation technologies [TRL 2]
- Enhanced food system with increased variety and acceptability [TRL 4]
- Hazard analysis critical control point processing [TRL 4]
- High barrier and low mass food packaging materials [TRL 2]
- Refined nutritional requirements [TRL 4]

</td></tr>
<tr><td>Research & Technology Questions [With Mission Priority]:</td><td>

No.	Question
38a	What procedures (e.g., storage, processing, preparation, clean-up), such as HACCP, need to be developed to assure a safe food system? **[ISS 1, Lunar 1, Mars 1]**
38b	What are the allowable limits of microbial and chemical contamination in the food? **[ISS 1, Lunar 1, Mars 1]**
38c	How does space radiation affect the functionality and nutritional content of the crops and stored staple ingredients for food processing? **[ISS N/A, Lunar 1, Mars 1]**
38d	What food processing technologies are required when using crops and stored staple ingredients to ensure a food system that is nutritious, safe and acceptable? **[ISS N/A, Lunar 1, Mars 1]**
38e	What food packaging materials will provide the physical and chemical attributes, including barrier properties, to protect the food from the outside environment and assure the 3-5 year shelf life? **[ISS 1, Lunar 1, Mars 1]**
38f	What food packaging material will be biodegradable, easily processed, or be lighter in mass than the current packaging and can still provide the physical and chemical attributes including barrier properties to protect the food from the outside environment and assure the 3-5 year shelf life? **[ISS 1, Lunar 1, Mars 1]**
38g	What food preservation technologies will provide prepackaged food items with a shelf life of 3-5 years? **[ISS 2, Lunar 2, Mars 2]**
38h	What are the impacts of reduced Gravity and atmospheric pressure on the food processing activities? **[ISS N/A, Lunar 2, Mars 1]**
38i	What are the impacts of reduced Gravity and atmospheric pressure on the food preparation activities? **[ISS 3, Lunar 2, Mars 1]**
38j	What nutritional content and sensory attribute changes (including radiation-induced effects) in the prepackaged food items will occur over the shelf life of the food? **[ISS 2, Lunar 2, Mars 2]**
38k	What food system technology selection criteria will be used to effectively reduce the use of critical resources such as air, water, thermal, biomass and solid waste processing, during a mission? **[ISS 2, Lunar 2, Mars 2]**
38l	What are the changes (taste, odor, etc.) that occur in crewmember's sensory perceptions during space flight that would affect food acceptability? **[ISS 3, Lunar 3, Mars 3]**
38m	What are the physical and chemical requirements for each of the crops and stored staple ingredient items to assure effective processing into acceptable, safe and nutritious food ingredients? **[ISS N/A, Lunar 2, Mars 2]**
38n	What level of acceptability and/or variety (e.g., number of food items, length of menu cycle) is required to provide for the psychosocial well-being of the crew? **[ISS 3, Lunar 3, Mars 2]**

</td></tr>
</table>

	38o	What modeling techniques can be used to measure the subjective portions of the food system such as palatability, nutrition, psychological issues and variety? **[ISS 3, Lunar 3, Mars 2]**
Related Risks :		**Cardiovascular Alterations**
		Occurrence of Serious Cardiac Dysrhythmias
		Environmental Health
		Define Acceptable Limits for Contaminants in Air and Water
		Immunology & Infection
		Immune Dysfunction, Allergies and Autoimmunity
		Interaction of Space flight Factors, Infections and Malignancy
		Skeletal Muscle Alterations
		Reduced Muscle Mass, Strength, and Endurance
		Nutrition
		Inadequate Nutrition
		Behavioral Health & Performance and Space Human Factors (Cognitive)
		Human Performance Failure Due to Poor Psychosocial Adaptation
		Human Performance Failure Due to Neurobehavioral Problems
		Radiation
		Acute Radiation Risks
		Advanced Environmental Monitoring & Control
		Monitor Surfaces, Food, and Soil
		Advanced Life Support
		Maintain Thermal Balance in Habitable Areas
		Manage Waste
		Provide and Maintain Bioregenerative Life Support Systems
		Provide and Recover Potable Water
Important References :		Isolation NASA Experiments in Closed-Environment Living Advanced Human Life Support Enclosed System Volume 104SCIENCE AND TECHNOLOGY SERIES; A Supplement to Advances in the Astronautical Sciences Edited by: Helen W. Lane, Richard L. Sauer, and Daniel L. Feeback. Published for the American Astronautical Society by Univelt, Incorporated, P.O. Box 28130, San Diego, California 92198 web: http://lsda.jsc.nasa.gov/books/ground/chambers.pdf. web:%20%20http://lsda.jsc.nasa.gov/books/ground/chambers.pdf
		Kerwin J, and Seddon R. (2002). Eating in Space - From an Astronaut's Perspective. Nutrition 18 (10):913-920. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=12361788
		M Perchonok, S French, B Swango, V Kloeris, D Barta, M Lawson, J Joshi. Advanced Food Technology Workshop Report Volume I, NASA/CP-2003-212055, 2003.
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	U. S. Food and Drug Administration. Kinetics of Microbial Inactivation for Alternative Food Processing Technologies. http://vm.cfsan.fda.gov/~comm/ift-toc.html. June 2000. http://vm.cfsan.fda.gov/~comm/ift-toc.html

Risk Title: Maintain Acceptable Atmosphere

Crosscutting Area :	Advanced Human Support Technologies (AHST)
Discipline :	Advanced Life Support
Risk Number :	39
Risk Description :	Crew health may be compromised due to inability of currently available technology to monitor and control spacecraft atmosphere. Risk may be mitigated by development of new technologies that will be integrated into the life support systems.
Context / Risk Factors :	This risk may be influenced by complexity of systems and increase in the number of systems (e.g., additional solid waste processing, plant growth, food processing, etc.), insensitivity of control system to contaminants leading to toxic build-ups due to a closed system, remoteness, or severely constrained resources (such as mass, power, volume, thermal, crew time).
Justification / Rationale :	The inability to control and condition the atmosphere and maintain the makeup & composition, limits the ability of the crew to perform basic functions and can present an immediate threat to the health, life and success of crew and mission.
Risk Rating :	**ISS:** Priority 3 **Lunar:** Priority 2 **Mars:** Priority 1
Current Countermeasures :	• Consumables re-supply • Technology development to further close the air loop and increase carbon dioxide reduction, which includes testing, modeling and analysis
Projected Countermeasures or Mitigations & other Deliverables:	• Bioregenerative Life Support [Lunar] [Mars] • CO2 Moisture Removal System [TRL 4] [Lunar] [Mars] • Improved Carbon Dioxide Removal and Reduction System [TRL 3-4] • In-Situ Resource Utilization [Lunar] [Mars] • Regenerable Trace Contaminant Control System [TRL 4] • Better models to identify contaminant load [Lunar] [Mars]
Research & Technology Questions [With Mission Priority]:	**No.** / **Question** 39a: What new developments are needed to meet all the requirements for controlling trace contaminants, atmospheric pressure, O2 and CO2 partial pressure? **[ISS 1, Lunar 1, Mars 1]**

	39b	What method for closing the O2 loop is most effective in an integrated ECLS? **[ISS 2, Lunar 2, Mars 2]**
	39c	What is the proper trace contaminant load and performance model to drive the design and operation of a trace contaminant system? **[ISS 2, Lunar 2, Mars 2]**
	39d	Can viability and genetic integrity of the biological components be maintained for the duration of different missions? **[ISS 4, Lunar 3, Mars 2]**
	39e	What are the effects of radiation on biological components of the life support system? **[ISS 3, Lunar 3, Mars 1]**
	39f	What research is required to validate design approaches for multiphase flow and particulate flows for air revitalization systems in varying gravity environments? **[ISS 3, Lunar 3, Mars 3]**

Related Risks :	**Environmental Health**
	Define Acceptable Limits for Contaminants in Air and Water
	Radiation
	Acute Radiation Risks
	Advanced Environmental Monitoring & Control
	Monitor Air Quality
	Monitor Water Quality
	Monitor Surfaces, Food, and Soil
	Provide Integrated Autonomous Control of Life Support Systems
	Advanced Life Support
	Maintain Thermal Balance in Habitable Areas
	Manage Waste
	Provide and Maintain Bioregenerative Life Support Systems
Important References :	Designing for Human Presence in Space: An Introduction to Environmental Control and Life Support Systems, NASA RP-1324, 1994
	Isolation, NASA Experiments in Closed-Environment Living, Advanced Human Life Support Enclosed System Final Report, Volume 104, Science And Technology Series, A Supplement to Advances in the Astronautical Sciences, Edited by Helen W. Lane, Richard L. Sauer and Daniel L. Feeback. Published for the American Astronautical Society by Univelt, Incorporated, P.O. Box 28130, San Diego, CA 92198. web: http://lsda.jsc.nasa.gov/books/ground/chambers.pdf http://lsda.jsc.nasa.gov/books/ground/chambers.pdf
	Space flight Life Support and Biospherics, Eckart, 1996

Risk Title: Maintain Thermal Balance in Habitable Areas

Crosscutting Area :	Advanced Human Support Technologies (AHST)
Discipline :	Advanced Life Support
Risk Number :	40
Risk Description :	Crew health may be compromised due to inability of currently available technology to provide crew module thermal control. Risk may be further mitigated by development of new technologies that will be integrated into the thermal control system.
Context / Risk Factors :	This risk may be influenced by location on a planetary surface, orientation of the vehicle during flight, orientation of vehicle and/or habitat on planetary surface, planetary environment (temperature ranges & extremes, dust, seasonal variations, etc.), sources of heat from other elements of the mission, and use or availability of local planetary resources.
Justification / Rationale :	Humans cannot live and work in space without a thermally controlled environment.

Risk Rating :	**ISS:** Priority 3 **Lunar:** Priority 2 **Mars:** Priority 1
Current Countermeasures :	• Thermal Control system
Projected Countermeasures or Mitigations & other Deliverables:	• Several advances are underway to improve the reliability and life, or decrease the mass, volume, or power required for thermal control system hardware (e.g. heat rejection devices, heat transport fluids, heat acquisition devices, heat transfer devices) [TRL 3-6]
Research & Technology Questions [With Mission Priority]:	(see table below)

No.	Question
40a	What heat transport fluids meet the requirements for specified missions? **[ISS 1, Lunar 1, Mars 1]**
40b	What materials and designs will meet the heat acquisition (cold plates, heat exchangers, cooling jackets, etc.) requirements for specified missions? **[ISS 1, Lunar 1, Mars 1]**
40c	What materials and designs will meet the heat transport (pumps, two-phase loops, heat pumps, etc.) requirements for specified missions? **[ISS 1, Lunar 1, Mars 1]**
40d	What materials and designs will meet the heat rejection (radiators, sublimators, evaporators, etc.) requirements for specified missions? **[ISS 1, Lunar 1, Mars 1]**
40e	What materials and designs will meet the humidity control requirements for specified missions? **[ISS 1, Lunar 1, Mars 1]**
40f	What thermal system sensors will meet the requirements to provide monitoring and data collection for specified missions? **[ISS 2, Lunar 2, Mars 2]**
40g	What monitoring and control system hardware and design will meet the requirements for specified missions? (AEMC) **[ISS 2, Lunar 2, Mars 2]**

Related Risks :

Advanced Environmental Monitoring & Control
Monitor Air Quality
Advanced Extravehicular Activity
Provide Space Suits and Portable Life Support Systems
Advanced Life Support
Maintain Acceptable Atmosphere

Important References :

Advanced Technology of Human Support in Space, Committee on Advanced Technology for Human Support in Space, Aeronautics and Space Engineering Board, National Research Council, National Academy Press, Washington DC, 1997.
Designing for Human Presence in Space: An Introduction to Environmental Control and Life Support Systems, NASA RP-1234, 1994.
Isolation, NASA Experiments in Closed-Environment Living, Advanced Human Life Support Enclosed System Final Report, Volume 104, Science And Technology Series, A Supplement to Advances in the Astronautical Sciences, Edited by Helen W. Lane, Richard L. Sauer and Daniel L. Feeback. Published for the American Astronautical Society by Univelt, Incorporated, P.O. Box 28130, San Diego, CA 92198. web: http://lsda.jsc.nasa.gov/books/ground/chambers.pdf http://lsda.jsc.nasa.gov/books/ground/chambers.pdf
Space flight Life Support and Biospherics, Eckart, 1996.

Risk Title: Manage Waste

Crosscutting Area :	Advanced Human Support Technologies (AHST)
Discipline :	Advanced Life Support
Risk Number :	41

<table>
<tr><td>Risk Description :</td><td>Crew health may be compromised due to inability of currently available technology to adequately process solid wastes reliably with minimum power, mass, volume. Inadequate waste management can also lead to contamination of planetary surfaces.</td></tr>
<tr><td>Context / Risk Factors :</td><td>This risk may be influenced by crew health, crew susceptibility to the degree of system closure, mission duration, the microgravity environment, failure of other systems such as diminished or failed power supply, or remoteness.</td></tr>
<tr><td>Justification / Rationale :</td><td>Inadequate waste management can result in crew health and safety concerns, including reduced performance and sickness. Inadequate waste management can also lead to contamination of planetary surfaces, or significant increases in mission costs in terms of system mass, power, volume and consumables.</td></tr>
<tr><td>Risk Rating :</td><td>ISS: Priority 3
Lunar: Priority 2
Mars: Priority 1</td></tr>
<tr><td>Current Countermeasures :</td><td>• Adsorbents are used for odor control
• Crew manually compacts waste and/or stores waste in bags
• Feces is mechanically compacted
• Waste is returned to Earth in the Space Shuttle for disposal, or returned in expendable logistics modules to be destroyed on entry</td></tr>
<tr><td>Projected Countermeasures or Mitigations & other Deliverables:</td><td>• Current practice though less than optimal may be adequate for the life of ISS
• Provide a system for adequately collecting waste . [TRL 2] [Lunar] [Mars]
• Provide a system for adequately transporting waste [TRL 2] [Lunar] [Mars]
• Provide a system for processing waste for storage , resource recovery or disposal of trash generated (including clothing) throughout the mission, reliably and efficiently with minimum power, mass and volume. [TRL 2] [Lunar] [Mars]</td></tr>
<tr><td>Research & Technology Questions [With Mission Priority]:</td><td>
<table>
<tr><th>No.</th><th>Question</th></tr>
<tr><td>41a</td><td>What system will meet the storage and/or disposal requirements for specified missions? [ISS 1, Lunar 1, Mars 1]</td></tr>
<tr><td>41b</td><td>What system will meet requirements for processing wastes to recover resources for specified missions? [ISS 1, Lunar 1, Mars 1]</td></tr>
<tr><td>41c</td><td>What waste management will handle complex waste streams such as packaging, paper, etc. in order to meet mission requirements? [ISS 2, Lunar 2, Mars 2]</td></tr>
<tr><td>41d</td><td>What waste management will handle medical wastes such as blood, tissues and syringes etc. in order to meet mission requirements? [ISS 2, Lunar 2, Mars 2]</td></tr>
<tr><td>41e</td><td>What system will meet the requirements for managing residuals for planetary protection? [ISS 1, Lunar 1, Mars 1]</td></tr>
<tr><td>41f</td><td>How can microbes and candidate crop species be engineered to perform better and fulfill multiple functions in a bioregenerative system? [ISS 4, Lunar 3, Mars 1]</td></tr>
<tr><td>41g</td><td>What are the interfaces between the biological and physical chemical life support subsystems for a specified mission? [ISS 3, Lunar 3, Mars 1]</td></tr>
<tr><td>41h</td><td>Can viability and genetic integrity of the biological components be maintained for the duration of different missions? [ISS 4, Lunar 3, Mars 2]</td></tr>
<tr><td>41i</td><td>How do partial and microgravity affect biological waste processing? [ISS 4, Lunar 3, Mars 1]</td></tr>
<tr><td>41j</td><td>What are the effects of radiation on biological components of the life support system? [ISS 3, Lunar 3, Mars 1]</td></tr>
<tr><td>41k</td><td>What sensors are required to monitor performance and provide inputs to control systems (AEMC)? [ISS 2, Lunar 2, Mars 2]</td></tr>
</table>
</td></tr>
</table>

	<table><tr><td>41l</td><td>What monitoring and control system can provide semi to total autonomous control to relieve the crew of monitoring and control functions to the extent possible (AEMC)? **[ISS 2, Lunar 2, Mars 2]**</td></tr><tr><td>41m</td><td>What studies need to be performed to determine whether or not recycling of solid waste can be done cost effectively to provide building materials for habitability features needed in subsequent phases of specified missions? **[ISS 5, Lunar 3, Mars 3]**</td></tr><tr><td>41n</td><td>What research is required to validate design approaches for multiphase flows for solid waste management and resource recovery in varying gravity environments. **[ISS 3, Lunar 3, Mars 3]**</td></tr><tr><td>41o</td><td>What resources are required to manage waste disposal as an environmental risk during long and remote missions (from EH)? **[ISS 4, Lunar 3, Mars 1]**</td></tr><tr><td>41p</td><td>What system will meet requirements for processing wastes to recover water for specified missions? **[ISS 1, Lunar 1, Mars 1]**</td></tr><tr><td>41q</td><td>What system will meet requirements for processing wastes to recover CO2 for specified missions? **[ISS 1, Lunar 1, Mars 1]**</td></tr><tr><td>41r</td><td>What system will meet requirements for processing wastes to recover minerals for specified missions? **[ISS 1, Lunar 1, Mars 1]**</td></tr><tr><td>41s</td><td>How should wastes be handled or stored to avoid perception such as bad odors or unsightly appearance that would adversely affect crew quality of life and consequent degradation in performance? **[ISS 2, Lunar 2, Mars 2]**</td></tr><tr><td>41t</td><td>What waste management systems will prevent release of biological material (cells or organic chemicals that are signs of life) from contaminating a planetary surface, such as the Martian surface, and compromising the search for indigenous life? **[ISS N/A, Lunar 4, Mars 1]**</td></tr><tr><td>41u</td><td>What management systems will prevent release of biological materials that could harm indigenous biological communities? **[ISS 3, Lunar 2, Mars 1]**</td></tr><tr><td>41v</td><td>What is the probability that waste materials could become reservoirs for return of indigenous life to Earth (i.e. backward contamination)? What systems can prevent this from occurring? **[ISS N/A, Lunar N/A, Mars 1]**</td></tr><tr><td>41w</td><td>What is the probability that microorganisms in biological wastes such as food scraps or feces could be altered or mutated by the space environment radiation to become harmful or pathogenic? What can prevent this? **[ISS 4, Lunar 3, Mars 2]**</td></tr><tr><td>41x</td><td>What containment vessels will be sufficient to prevent escape of stored waste at various mission locations such as planetary surfaces or crew cabins? **[ISS 4, Lunar 3, Mars 1]**</td></tr></table>
Related Risks :	**Immunology & Infection** Alterations in Microbes and Host Interactions **Nutrition** Inadequate Nutrition **Radiation** Acute Radiation Risks **Advanced Life Support** Maintain Acceptable Atmosphere Provide and Maintain Bioregenerative Life Support Systems Provide and Recover Potable Water
Important References :	Advanced Technology of Human Support in Space, Committee on Advanced Technology for Human Support in Space, Aeronautics and Space Engineering Board, National Research Council, National Academy Press, Washington DC, 1997. Designing for Human Presence in Space: An Introduction to Environmental Control and Life Support Systems, NASA RP-1324, 1994.

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Risk Title: Provide and Maintain Bioregenerative Life Support Systems

Crosscutting Area :	Advanced Human Support Technologies (AHST)
Discipline :	Advanced Life Support
Risk Number :	42
Risk Description :	Sustaining crew health and performance may be compromised by lack of bioregenerative systems.
Context / Risk Factors :	This risk may be influenced by the effect of radiation on plants, reduced atmospheric pressure, reduced sunlight, limited availability of water, limits on power availability for artificial lighting, reduced gravity, or remoteness.
Justification / Rationale :	For ISS, the re-supply line is relatively short, on-board resources are limited for accommodating bioregenerative systems, and the risk to crew performance and mission success is relatively low. For the moon, bioregenerative systems would be advantageous to sustain long-term habitats on the Lunar surface due to cost and contingencies required for re-supply. For Mars, very high life support resupply costs would be necessary for a long-term Martian habitat without bioregenerative systems. Bioregenerative systems would be the only means of producing food and a primary contributor for CO2 removal, O2 production, and H2O purification and achieving high degree of autonomy.
Risk Rating :	**ISS:** Priority 3 **Lunar:** Priority 2 **Mars:** Priority 1
Current Countermeasures :	• Development of Vegetable Production Unit • Screen acceptable cultivars for space systems • Fresh fruit and vegetables included on current re-supply missions to ISS
Projected Countermeasures or Mitigations & other Deliverables:	• Integrated Bioregenerative / PC test bed [TRL 3] [Mars] • Low pressure Martian greenhouse [TRL 3] [Mars] • Mixed cropping systems for continuous production evaluated [TRL 5] [Lunar] • Provide Vegetable Production Unit for ISS [TRL 5] • Scale system to meet all O2 and CO2 requirements for surface habitat, and to meet partial food requirements. [CRL 6] [Mars] • Scale gravity-based salad production module to meet all water and O2 requirements for surface missions, and to meet food requirements [TRL 4] [Lunar]
Research & Technology Questions [With Mission Priority]:	

No.	Question
42a	What are the optimal methods of plant growth for a specified mission, including development of appropriate hardware, management of light, water, nutrients, gas composition and pressure, trace contaminants, horticultural procedures and disease risks? **[ISS 2, Lunar 2, Mars 1]**
42b	How can microbes and candidate crop species be engineered to perform better and fulfill multiple functions in a bioregenerative system? **[ISS 4, Lunar 3, Mars 1]**
42c	What mechanized or automated systems are required for planting, harvesting, monitoring, and controlling crops for a specified mission? **[ISS 4, Lunar 3, Mars 2]**

	<table><tr><td>42d</td><td>Can viability and genetic integrity of the biological components be maintained for the duration of different missions? [ISS 4, Lunar 3, Mars 2]</td></tr><tr><td>42e</td><td>What are the interfaces between the biological and physical chemical life support subsystems for a specified mission? [ISS 4, Lunar 3, Mars 1]</td></tr><tr><td>42f</td><td>How do partial and microgravity affect plant growth and crop yield? [ISS 4, Lunar 3, Mars 1]</td></tr><tr><td>42g</td><td>What are the effects of radiation on biological components of the life support system? [ISS 3, Lunar 3, Mars 1]</td></tr><tr><td>42h</td><td>What percentage of crew food needs should be attributed to ALS plant products for specified missions? [ISS 5, Lunar 3, Mars 2]</td></tr><tr><td>42i</td><td>What capabilities and associated hardware are required for processing and storing plant products for a specified mission? [ISS 5, Lunar 3, Mars 2]</td></tr><tr><td>42j</td><td>Can the plant production rates and ALS functions be sustained for the duration of the mission? [ISS 5, Lunar 3, Mars 1]</td></tr><tr><td>42k</td><td>Can plant yields and ALS functions measured during low TRL (fundamental) testing be scaled up for large bioregenerative systems? [ISS 5, Lunar 3, Mars 1]</td></tr><tr><td>42l</td><td>What sensors and monitoring systems will be required to measure environmental conditions and crop growth parameters and health for a specified mission (AEMC)? [ISS 3, Lunar 3, Mars 2]</td></tr><tr><td>42m</td><td>What control system hardware and software technologies will be required to monitor and control crop systems for a specified mission (AEMC)? [ISS 3, Lunar 3, Mars 2]</td></tr></table>
Related Risks :	<table><tr><td>Environmental Health</td></tr><tr><td>Define Acceptable Limits for Contaminants in Air and Water</td></tr><tr><td>Nutrition</td></tr><tr><td>Inadequate Nutrition</td></tr><tr><td>Radiation</td></tr><tr><td>Acute Radiation Risks</td></tr><tr><td>Advanced Environmental Monitoring & Control</td></tr><tr><td>Monitor Air Quality</td></tr><tr><td>Monitor Water Quality</td></tr><tr><td>Provide Integrated Autonomous Control of Life Support Systems</td></tr><tr><td>Advanced Extravehicular Activity</td></tr><tr><td>Provide Space Suits and Portable Life Support Systems</td></tr><tr><td>Advanced Life Support</td></tr><tr><td>Maintain Acceptable Atmosphere</td></tr><tr><td>Manage Waste</td></tr><tr><td>Provide and Recover Potable Water</td></tr></table>
Important References :	<table><tr><td>Advanced Technology of Human Support in Space, Committee on Advanced Technology for Human Support in Space, Aeronautics and Space Engineering Board, National Research Council, National Academy Press, Washington DC, 1997.</td></tr><tr><td>Designing for Human Presence in Space: An Introduction to Environmental Control and Life Support Systems, NASA RP-1324, 1994.</td></tr></table>

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	Space flight Life Support and Biospherics, Eckart, 1996.
	Wheeler RM, CL Mackowiak, GS Stutte, NC Yorio, LM Ruffe, JC Sager, RP Prince, BV Peterson, GD Goins, WL Berry, CR Hinkle and WM Knott. 2003. Crop production for Advanced Life Support Systems. Observations from the Kennedy Space Center Breadboard Project. NASA Tech. Mem. 2003-211184. (58 pages).
	Wheeler RM, GW Stutte, GV Subbarao and NC Yorio. 2001. Plant growth and human life support for space travel. In: M. Pessarakli (ed.), 2nd Edition. Handbook of Plant and Crop Physiology. pp. 925-941. Marcel Dekker Inc., NY.
	Wheeler, R.M. and C. Martin-Brennan. 2000. Martian greenhouses: Concept and Challenges. Proceedings from a 1999 Workshop. NASA Tech. Memorandum 208577.

Risk Title: Provide and Recover Potable Water

Crosscutting Area :	Advanced Human Support Technologies (AHST)
Discipline :	Advanced Life Support
Risk Number :	43
Risk Description :	Crew health may be compromised due to inability of currently available technology to adequately provide and recover potable water.
Context / Risk Factors :	This risk may be influenced by crew health, crew susceptibility to the degree of system closure, or remoteness.
Justification / Rationale :	Lack of potable water is a health risk. For Lunar and Mars missions, the lack of immediate re-supply and increased reliance on water recovery systems compounds the risk.
Risk Rating :	**ISS:** Priority 3 **Lunar:** Priority 2 **Mars:** Priority 1
Current Countermeasures :	• Stored potable water onboard spacecraft • Water recovery system performance monitored • Re-supply of potable water from Earth
Projected Countermeasures or Mitigations & other Deliverables:	• Biological systems [TRL 4] • Possibility of in-situ resource utilization (cannot assign TRL until presence of water is confirmed) • Redundant systems [TRL 2]
Research & Technology Questions [With Mission Priority]:	

No.	Question
43a	What system meets all requirements for supplying potable water needs? **[ISS 1, Lunar 1, Mars 1]**
43b	What mechanisms to collect and transport wastewater meet the mission requirements? **[ISS 1, Lunar 1, Mars 1]**
43c	What methods for the removal of organic, inorganic and microbial contaminants in wastewater meet all mission requirements for efficiency and reliability? **[ISS 1, Lunar 1, Mars 1]**
43d	What method to store and maintain portability of recycled water meets all requirements for specified missions? **[ISS 1, Lunar 1, Mars 1]**

	<table><tr><td>43e</td><td>What sensors are required to provide water quality parameters, monitor performance and provide inputs to a control system (AEMC)? **[ISS 2, Lunar 2, Mars 2]**</td></tr><tr><td>43f</td><td>What control system meets all mission requirements (AEMC)? **[ISS 2, Lunar 2, Mars 2]**</td></tr><tr><td>43g</td><td>How can microbes be engineered to perform better and fulfill multiple functions in a bioregenerative system? **[ISS 5, Lunar 3, Mars 1]**</td></tr><tr><td>43h</td><td>What are the interfaces between the biological and physical chemical life support subsystems for a specified mission? **[ISS 5, Lunar 3, Mars 1]**</td></tr><tr><td>43i</td><td>Can viability and genetic integrity of the biological components be maintained for the duration of different missions? **[ISS 5, Lunar 3, Mars 2]**</td></tr><tr><td>43j</td><td>How do partial gravity and microgravity affect biological water processing? **[ISS N/A, Lunar 3, Mars 1]**</td></tr><tr><td>43k</td><td>What are the effects of radiation on biological components of the life support system? **[ISS 3, Lunar 3, Mars 1]**</td></tr><tr><td>43l</td><td>What research is required to validate design approaches for multiphase flows for Water recovery systems in varying gravity environments? **[ISS 1, Lunar 1, Mars 2]**</td></tr></table>
Related Risks :	<table><tr><td>**Nutrition**</td></tr><tr><td>Inadequate Nutrition</td></tr><tr><td>**Radiation**</td></tr><tr><td>Acute Radiation Risks</td></tr><tr><td>**Advanced Environmental Monitoring & Control**</td></tr><tr><td>Monitor Water Quality</td></tr><tr><td>Provide Integrated Autonomous Control of Life Support Systems</td></tr><tr><td>**Advanced Life Support**</td></tr><tr><td>Manage Waste</td></tr><tr><td>Provide and Maintain Bioregenerative Life Support Systems</td></tr></table>
Important References :	<table><tr><td>Advanced Technology of Human Support in Space, Committee on Advanced Technology for Human Support in Space, Aeronautics and Space Engineering Board, National Research Council, National Academy Press, Washington DC, 1997.</td></tr><tr><td>Designing for Human Presence in Space: An Introduction to Environmental Control and Life Support Systems, NASA RP-1234, 1994.</td></tr><tr><td>Isolation, NASA Experiments in Closed-Environment Living, Advanced Human Life Support Enclosed System Final Report, Volume 104, Science And Technology Series, A Supplement to Advances in the Astronautical Sciences, Edited by Helen W. Lane, Richard L. Sauer and Daniel L. Feeback. Published for the American Astronautical Society by Univelt, Incorporated, P.O. Box 28130, San Diego, CA 92198. web: http://lsda.jsc.nasa.gov/books/ground/chambers.pdf http://lsda.jsc.nasa.gov/books/ground/chambers.pdf</td></tr><tr><td>Space flight Life Support and Biospherics, Eckart, 1996.</td></tr></table>

Risk Title: Mismatch Between Crew Physical Capabilities and Task Demands

Crosscutting Area :	Advanced Human Support Technologies (AHST)
Discipline :	Space Human Factors Engineering
Risk Number :	44
Risk Description :	Human performance failure may occur due to human factors inadequacies in the physical work environments (e.g., workplaces, equipment, protective clothing, tools and tasks).
Context / Risk Factors :	Physical elements such as habitats, work environments, equipment, protective clothing, or tools can impact human performance in accomplishing tasks. Additionally, tasks not designed to

	accommodate human physical limitations, including changes in crew capabilities resulting from mission and task duration factors, may lead to crew injury or illness or reduced effectiveness or efficiency in nominal or predictable emergency situations. Performance may be further affected by state of fitness (and effectiveness of exercise countermeasures), training, and changing gravitational fields.
Justification / Rationale :	Crew accommodations are designed based primarily on volume and mass considerations. Anecdotal information from crew reports and extrapolations from physiological studies is available on impacts of habitats, work environments, workplaces, equipment, protective clothing, tools and tasks on human performance in space contexts. There is inadequate data on physical performance changes in strength, stamina and motor skill as functions of time in space flight environments. Returning crewmembers usually exhibit substantial physical and motor deficits. Performance will be enhanced through incorporation of human factors into vehicle, task and equipment design.
Risk Rating :	**ISS:** Priority 2 **Lunar:** Priority 2 **Mars:** Priority 1
Current Countermeasures :	• Appropriate mission design • Crew resiliency • Crew training
Projected Countermeasures or Mitigations & other Deliverables:	• Measurement, analysis, modeling and design tools for optimizing environment, habitat, workplace, equipment, protective clothing and task design [TRL 2] • Tools for analyzing physical tasks to determine allocations of functions between humans and machines [TRL 2]

Research & Technology Questions [With Mission Priority]:

No.	Question
44a	What are the effects of microgravity, 1/6-gravity, or 1/3-gravity on requirements for habitable volume and architecture? **[ISS 2, Lunar 2, Mars 2]**
44b	What designs of workspace, equipment, tool and clothing will accommodate differences in crew anthropometry? **[ISS 2, Lunar 2, Mars 2]**
44c	What are the effects of duration of exposure to microgravity, 1/6-gravity, 1/3-gravity on human physical performance? **[ISS 1, Lunar 1, Mars 1]**
44d	What tools, equipment and procedures will enable crew physical performance to accommodate the effects of exposure to different gravity levels? **[ISS 2, Lunar 2, Mars 2]**
44e	How can crewmembers and ground support personnel detect and compensate for decreased physical readiness to perform during a mission? **[ISS 2, Lunar 3, Mars 3]**
44f	What scheduling constraints are required to reduce the risk of human performance failure due to physical fatigue to an acceptable probability? **[ISS 2, Lunar 2, Mars 2]**
44g	What principles of task design and function allocation will result in operations concepts that meet crew performance requirements for the mission? **[ISS 2, Lunar 2, Mars 2]**
44h	What limitations are required on physical workload to enable crewmembers to complete physical tasks with an acceptable probability? **[ISS 1, Lunar 1, Mars 1]**
44i	What crew size, composition and task allocations are required to accomplish the reference missions? **[ISS 1, Lunar 1, Mars 1]**
44j	What design considerations are needed to accommodate effects of changes in gravity, including launch, reentry, lunar landing, lunar launch, Mars landing, Mars launch, and Earth return? **[ISS 1, Lunar 1, Mars 1]**

Related Risks :

Environmental Health
Define Acceptable Limits for Contaminants in Air and Water
Sensory-Motor Adaptation

	Impaired Sensory-Motor Capability to Perform Operational Tasks During Flight, Entry, and Landing Impaired Sensory-Motor Capability to Perform Operational Tasks After Landing and Throughout Re-Adaptation Motion Sickness **Behavioral Health & Performance and Space Human Factors (Cognitive)** Mismatch between Crew Cognitive Capabilities and Task Demands Human Performance Failure Due to Sleep Loss and Circadian Rhythm Problems **Advanced Environmental Monitoring & Control** Monitor Air Quality Provide Integrated Autonomous Control of Life Support Systems **Space Human Factors Engineering** Poorly Integrated Ground, Crew, and Automation Functions
Important References :	An Ergonomics Case Study: Manual Material Handling in Microgravity. M. Whitmore & T. D. McKay. Advances in Industrial Ergonomics and Safety VI. London: Taylor & Francis. 1994. Ergonomic Evaluation of a Spacelab Glovebox. M. Whitmore, T. D. McKay, & F. E. Mount. International Journal of Industrial Ergonomics, 16, pp. 155-164. 1995. Human Space flight: Mission Analysis and Design, eds. W.J. Larson, L.K. Pranke. McGraw Hill Space Technology Series. 1999. Set Phasers on Stun, S. Casey, Agean Publishing, 1993. Thornton WE, and Rummel JA. (1977). "Muscular Deconditioning and its Prevention in Space flight," Biomedical Results from Skylab, pp. 175-182, NASA SP-377. Webb Associates, (1978), Anthropometric Source Book, Vol. I. Anthropometry for Designers, pp. 1-76, NASA RP 1024. West JB. (2000). Physiology in microgravity. Journal of Applied Physiology. 89(1): 379-384. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=10904075

Risk Title: Poorly Integrated Ground, Crew, and Automation Functions

Crosscutting Area :	Advanced Human Support Technologies (AHST)
Discipline :	Space Human Factors Engineering
Risk Number :	45
Risk Description :	Mission performance failure may occur without adequate operational concepts, design requirements, and design tools for integration of multiple factors that affect mission performance, such as ground-crew interaction, communication time, and level of automation.
Context / Risk Factors :	This risk may be influenced by communication lag times, communication blackouts, or loss of skills due to extended time since training.
Justification / Rationale :	Inadequate design of human-automation systems is known to lead to human error, based on analysis of incidents in the nuclear power industry and commercial aviation (Evidence Level 3). "Mode error" has resulted in fatal accidents in commercial aviation (Evidence Level 2). At least two critical collisions between ISS and SRMS have been avoided only by real-time monitoring and intervention by mission control (Evidence Level 4).
Risk Rating :	**ISS:** Priority 2 **Lunar:** Priority 2 **Mars:** Priority 1
Current Countermeasures :	• None (ad hoc engineering judgment is used)
Projected	

Countermeasures or Mitigations & other Deliverables:	• Reliability measures and data for human performance [TRL 2] • Requirements for use of automated systems and for human-centered system design [TRL 2] • Tools for analyzing task requirements [TRL 2]
Research & Technology Questions [With Mission Priority]:	See table below

No.	Question
45a	What crew size and composition is required to accomplish the reference mission? (Shared - Integrated Testing supports) **[ISS 2, Lunar 1, Mars 1]**
45b	What principles and algorithms for allocating tasks to human crewmembers, ground support and onboard automated systems will reduce the probability of significant errors? (Shared - Integrated Testing supports) **[ISS 1, Lunar 1, Mars 1]**
45c	What automated tools and equipment are required to enable the crewmembers to accomplish the mission? **[ISS 2, Lunar 2, Mars 2]**
45d	How do crew size, communications restrictions, crew skills, scheduling constraints and reference mission task requirements affect the requirements for automation? **[ISS 1, Lunar 1, Mars 1]**
45e	What combinations of crew, ground and on-board automation capabilities will increase the likelihood of a successful mission? (Shared - Integrated Testing supports) **[ISS 1, Lunar 1, Mars 1]**
45f	What training and operational readiness assurance processes and implementations will increase likelihood of mission success? **[ISS 2, Lunar 2, Mars 2]**
45g	What principles of task assignment workload and automation need to be developed to facilitate critical team performance? **[ISS 2, Lunar 2, Mars 2]**
45h	What tools and procedures are needed to determine the appropriate level of automation and crew control for the various tasks in the reference missions? **[ISS 1, Lunar 1, Mars 1]**

Related Risks :

Clinical Capabilities
Medical Informatics, Technologies, and Support Systems
Medical Skill Training and Maintenance
Behavioral Health & Performance and Space Human Factors (Cognitive)
Human Performance Failure Due to Poor Psychosocial Adaptation
Human Performance Failure Due to Neurobehavioral Problems
Mismatch between Crew Cognitive Capabilities and Task Demands
Human Performance Failure Due to Sleep Loss and Circadian Rhythm Problems
Advanced Environmental Monitoring & Control
Provide Integrated Autonomous Control of Life Support Systems
Space Human Factors Engineering
Mismatch Between Crew Physical Capabilities and Task Demands

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Human Performance Measures Handbook V.J.Gawron. Lawrence Erlbaum Associates: 2000.
Human Space flight: Mission Analysis and Design, eds. W.J. Larson, L.K. Pranke. McGraw Hill Space Technology Series. 1999.
Normal Accidents, Charles Perrow. 2001.
Sheridan TB. Humans and Automation: System Design and Research Issues. Wiley: 2003.

	The Effect of Automated Intelligent Advisors on Human Decision-making in Monitoring Complex Mechanical Systems. K O'Brien, EM Feldman, & FE Mount. Proceedings of HCI International 1993: 5th International Conference on Human-Computer Interaction. Elsevier Science Publishers. 1993.